AFRL-HE-WP-TR-2006-0129

THE SAFIRE AND AN INITIAL NETWORK-CENTRIC WARFARE EVALUATION

Michael W. Haas
Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

Matthew S. Middendorf
Middendorf Scientific Services, Inc.
Medway OH 45341

Shari Ulring
Advanced Information Systems
General Dynamics
Dayton OH 45431

August 2006

Interim Report for the period August 2003 to July 2006

DESTRUCTION NOTICE – Destroy by any method that will prevent disclosure of contents or reconstruction of this document.

Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Collaborative Interfaces Branch
Wright Patterson AFB OH 45433

NOTICE

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2006- 0129

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

FOR THE DIRECTOR

//signed//

DANIEL G GODDARD
Chief, Warfighter Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
1 Aug 2006

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
August 2003 – July 2006

4. TITLE AND SUBTITLE
The SAFIRE and an Initial Network-centric Warfare Evaluation

5a. CONTRACT NUMBER
In-House

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
Michael W. Haas *
Matthew S. Middendorf **
Shari Ulring ***

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
08

5f. WORK UNIT NUMBER
72

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Advanced Information Systems ***
General Dynamics
Dayton OH 45431

Middendorf Scientific Services, Inc **
Medway OH 45341

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command *
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Collaborative Interfaces Branch
Wright Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECP

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-HE-WP-TR-2006-0129

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
AFRL/PA Cleared 9-18-06, AFRL/WS 06-2216.

14. ABSTRACT
Two major purposes are served by this report. The first is to describe the Synthesized and Human Aerospace Forces in an immersive Research Environment (SAFIRE), a simulation capability linking many of the Warfighter Interface Division’s (AFRL/HEC) human-in-the-loop simulations together as well as with external AFRL and AFMC assets. The second purpose is to document the initial use of the SAFIRE architecture in its intended role, as a tool supporting evaluations of crew-system interfaces used in a network-centric environment. Information availability was manipulated experimentally during simulated air-to-air combat simulations of an air base defense mission scenario that involved multiple friendly and adversary aircraft as well as simulated airborne command and control. Statistical analysis of resultant data indicated that the manipulation of information availability did affect both objective measures of performance and subjective measures of situation awareness. The presence of these effects clearly demonstrates SAFIRE’s ability to support crew-system interface evaluations. In addition, the presence of a practice effect was observed indicating more attention should be focused on experimental design issues for future studies to reduce this effect or to compensate for its presence.

15. SUBJECT TERMS
Network-Centric Warfare, HCI, HMI, Information Availability, Air Combat, Command and Control

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. Michael W. Haas
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER (*Include area code*)
U	U	U	SAR	57	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

This page intentionally left blank.

Executive Summary

Two major purposes are served by this report. The first is to describe the Synthesized and Human Aerospace Forces in an Immersive Research Environment (SAFIRE), a simulation capability linking many of the Warfighter Interface Division's (AFRL/HEC) human-in-the-loop simulations together as well as with external AFRL and AFMC assets. The second purpose is to document the initial use of the SAFIRE architecture in its intended role, as a tool supporting evaluations of crew-system interfaces used in a network-centric environment.

Information availability was manipulated experimentally during simulated air-to-air combat simulations of an air base defense mission scenario that involved multiple friendly and adversary aircraft as well as simulated airborne command and control. Statistical analysis of resultant data indicated that the manipulation of information availability did affect both objective measures of performance and subjective measures of situation awareness. The presence of these effects clearly demonstrates SAFIRE's ability to support crew-system interface evaluations. In addition, the presence of a practice effect was observed indicating more attention should be focused on experimental design issues for future studies to reduce this effect or to compensate for its presence.

The extensive implications of network-centric operations on the design and use of crew interfaces for current and future Air Force systems is documented in the literature. The SAFIRE is a powerful tool to investigate these implications in highly complex and dynamic system-of-systems contexts.

This page intentionally left blank.

Table of Contents

List of Figures

1. INTRODUCTION

This technical report has two purposes. First, to describe the Synthesized and Human Aerospace Forces in an Immersive Research Environment (SAFIRE). Second, to describe the initial network-centric warfare experiment conducted in the SAFIRE. The SAFIRE has an innovative simulation capability for the study, development and evaluation of crew-system interfaces for network-centric operations and its initial use for this purpose will be described in this report.

1.1 Network-Centric Warfare Background

The United States Department of Defense (DoD) has indicated that the military must transform itself to more effectively deal with current threats. Two examples of this indication can be found throughout Joint Vision 2010 (JV2010, 1996) and Joint Vision 2020 (JV2020, 2000) as the need to move away from a platform-centric force to a network-centric force.

One definition of network-centric warfare (NCW) is “an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self synchronization.”(Alberts, 2000). Network-centric warfare is enabled by technologies that enhance the gathering, analysis, fusion, and distribution of information. The benefits of NCW are realized when the decision quality of information is improved in content, format, and timeliness, and can support varying degrees of autonomy when necessary. The NCW model that Alberts has visualized is shown in Figure 1.

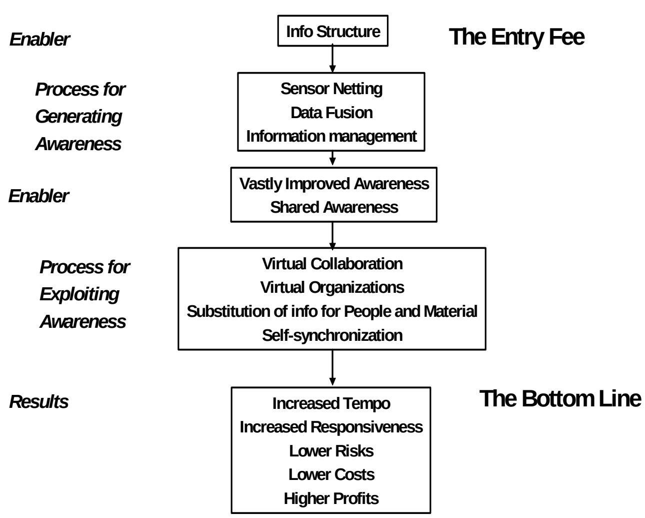


Figure 1-Albert’s Model of Network Centric Operations

The NCW concept of operation is transformational in the sense if moves defense forces from platform-centric operations to information-centric operations. There are a significant number of human factors challenges inherent in its implementation due in part, to the increases of information sources and sinks (Mitchell, 2004). While the increases in information flow and availability in network centric environments may improve individual and shared situation awareness, they may also increase the overall workload and stress level of individual crew members. The introduction of new NCW concepts into any battlespace should be carefully considered with respect to the Yerkes-Dobson Law, a commonly referenced human characteristic is shown in Figure 2.

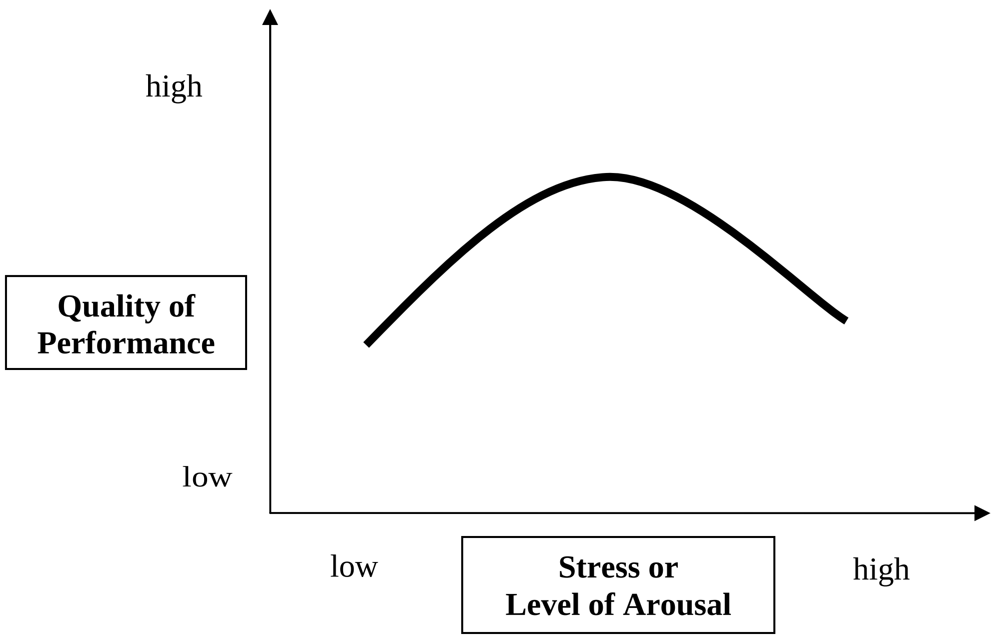


Figure 2-Yerkes-Dodson Law

The Yerkes-Dodson Law simply states that performance is a non-linear function of stress and/or the level of arousal (Boff, 1988). As can be seen in Figure 2, performance can be negatively affected by a stress level that is “too high” or “too low”. Mitchell *et a*l equates stress with workload and depicts the Yerkes-Dodson Law describing performance as a function of workload (Mitchell, 2004).

1.2 Initial NCW Study

Characteristics of network-centric warfare, specifically self-synchronization, are exhibited by pilots when flying air-to-air combat. Pilots continuously make decisions regarding their flight path through three dimensional airspace, their employment of offensive weapons, and their defensive tactics. This study measures human performance in simulated air combat, a “network-centric environment”, while attempting to vary workload by experimentally manipulating information availability to the pilot. In this experiment, crew members flew simulated air base defense missions under varying levels of visual and auditory information availability.

Information availability was manipulated by modifying sensor capability of the simulated aircraft and by the availability, or lack of, airborne command and control communications. The study utilized several components of the SAFIRE and fully exercised the architecture's functional capabilities.

It was hypothesized that the performance of the crews flying the air base defense missions would resemble a Yerkes-Dodson Law curve as the workload, or stress level, was manipulated by information availability. This presence of this effect is predicated on the assertion that manipulations employed in the current study span the sensitive region of the Yerkes-Dodson curve. If this is not the case, that in itself would have been interesting and would provide important guidance for follow-on studies.

1.3 SAFIRE

The Synthesized and Human Aerospace Forces in an Immersive Research Environment (SAFIRE) is a network of research assets including human-in-the-loop simulators, constructive simulations, battlespace visualization tools, and data collection and analysis capabilities. The SAFIRE is architected using distributed simulation techniques for the purpose of developing and evaluating crew interface concepts for network centric warfare. The SAFIRE's unique combination of simulation assets enables it to simulate many aspects of a joint warfighting environment and thus represents the complexities inherent in the operation of today's military systems-of-systems.

The purpose of the SAFIRE capability is to support the development and evaluation of crew interface concepts employed in network centric warfare. It is easily envisioned that crew interfaces, controls, displays, as well as underlying automation, required to optimize human performance in the information rich environment of network centric operations will provide affordances not previously required (Mitchell, 2004). In addition, truly innovative concepts of operations may be utilized in a network centric operation relative to today's relatively platform-centric operations. The ability of researchers to manipulate information availability and portrayal in the SAFIRE, and measure the resultant human performance effects, is the focus of this particular study. While the study is not an exhaustive study of each performance dimension of the SAFIRE, it is an end-to-end test along a single dimension.

2. SAFIRE DESCRIPTION

AFRL/HEC's Synthesized and Human Aerospace Forces in an Immersive Research Environment (SAFIRE) will be utilized during this evaluation. The SAFIRE is a combination of many interconnected human-in-the-loop (HITL) simulations and several constructive simulation software systems. The combination of constructive simulation and human-in-the-loop simulators provides the ability to simulate complex and dynamic battlefield situations involving air, sea, and ground components operating interactively in real-time. The full SAFIRE is depicted graphically in Figure 3.

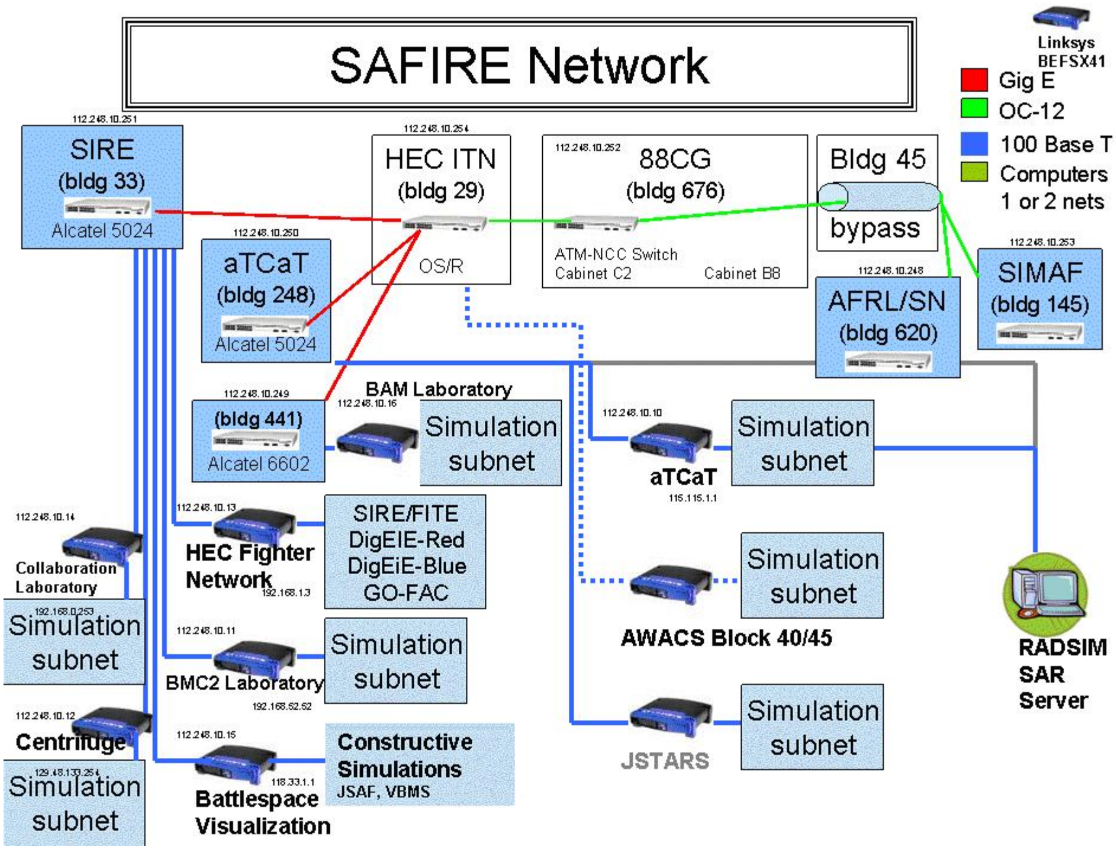


Figure 3. The SAFIRE is a collection of several facilities and assets in different buildings. Typically data within an end node is exchanged using the DIS protocol, and between nodes using HLA. The SAFIRE can accommodate complex NCW experiments.

The SAFIRE architecture was developed to be modular and scalable and enables each of the network end nodes to operate autonomously if needed. Within each end node, data is communicated between simulation components via the Distributed Interactive Simulation (DIS) protocol. Between end nodes, data is communicated using High Level Architecture (HLA) constructs. End nodes belonging to a common federation exchange HLA data using standard multicast techniques. The modular nature of the SAFIRE architecture is shown in Figure 4.

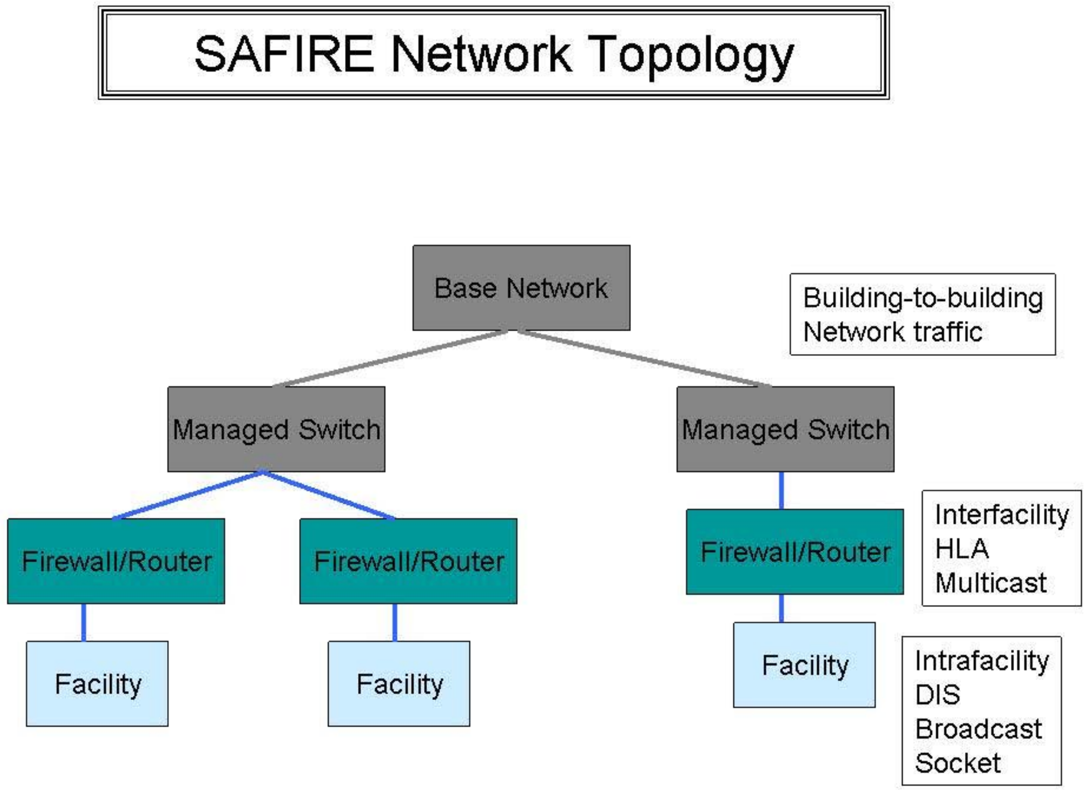


Figure 4. Structural framework of the SAFIRE network.

2.1 Facility Configuration for the Initial Study

Subsets of SAFIRE simulation capability can be used to satisfy the requirements of a specific test The SAFIRE simulation capability brought together for this evaluation is depicted in Figure 5 and includes a low fidelity controller station, two desktop air combat flight simulations, JSAF constructive simulation systems, and data collection systems.

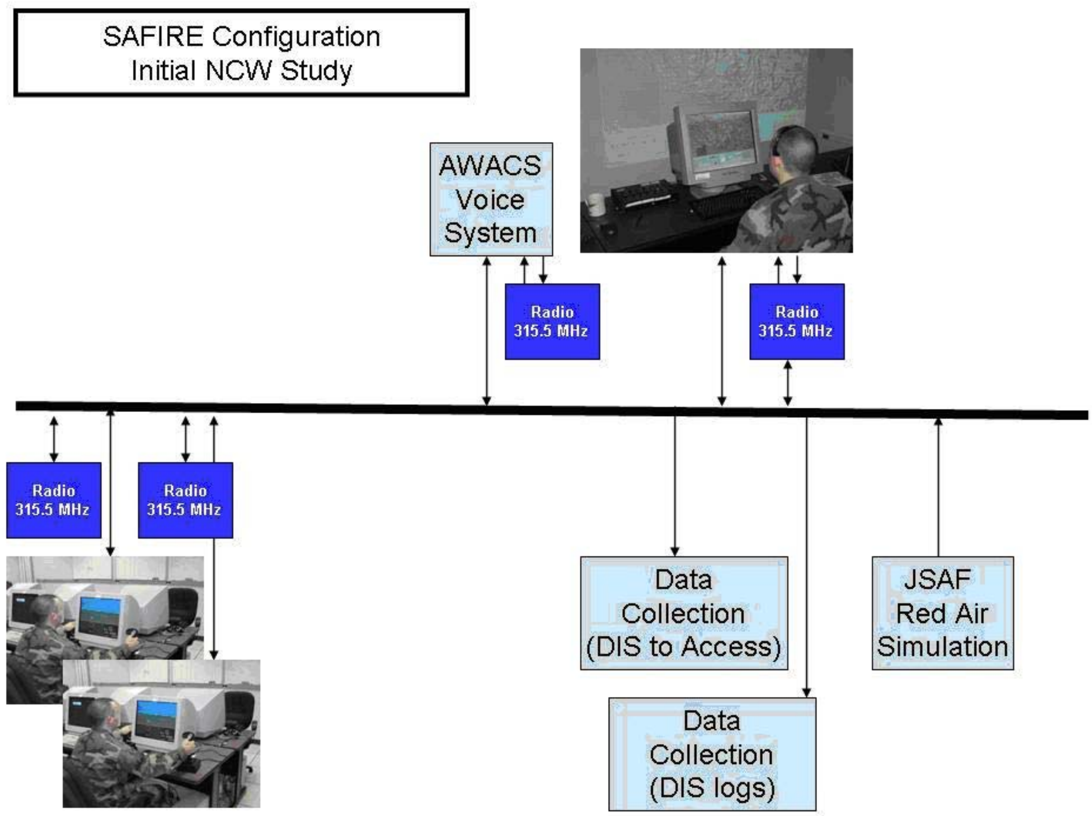


Figure 5. The initial NCW experiment used an airborne controller (in the battlespace visualization room), the JSAF constructive simulation tool, and two fighter simulations (in the DIGEIE Blue facility). Some data collection assets were also employed.

Table 1 matches the required simulation functionality with the method of generation for this evaluation.

Study Component	**Supplied by:**
Blue Fighter Aircraft	HITL simulation
Blue Airborne Controller	HITL simulation
Red Strike Aircraft	JSAF constructive simulation
Red Fighter Aircraft	JSAF constructive simulation
Data Collection	HLA Results and DIS Logger Software

Table 1 – Mapping of functionality to requirements

2.2 Blue Team Aircraft Simulators

The Blue team flew simulated fighter aircraft in the Digital Entities for Interface Evaluations – BLUE (DIG-EIE-BLUE) laboratory (Figure 6). DIG-EIE-BLUE is equipped with 6 Windows 2000 PCs. These systems run the SAFIRE Air Combat Simulator (SACS), an in-house modified air-to-air human-in-the-loop flight simulation (Figure 7). Radio communications are simulated using the General Dynamics ModIOS Voice Communicator software. Stick and throttle controls are achieved using the Thrustmaster F22 PRO, Advanced Control Series Joystick and SunComm Strike Fighter Series Throttle.

Figure 6. The air-to-air combat simulators used for the blue team are hosted on desktop PCs. The simulators communicate with each other using the Distributed Interactive Simulation (DIS) protocol.

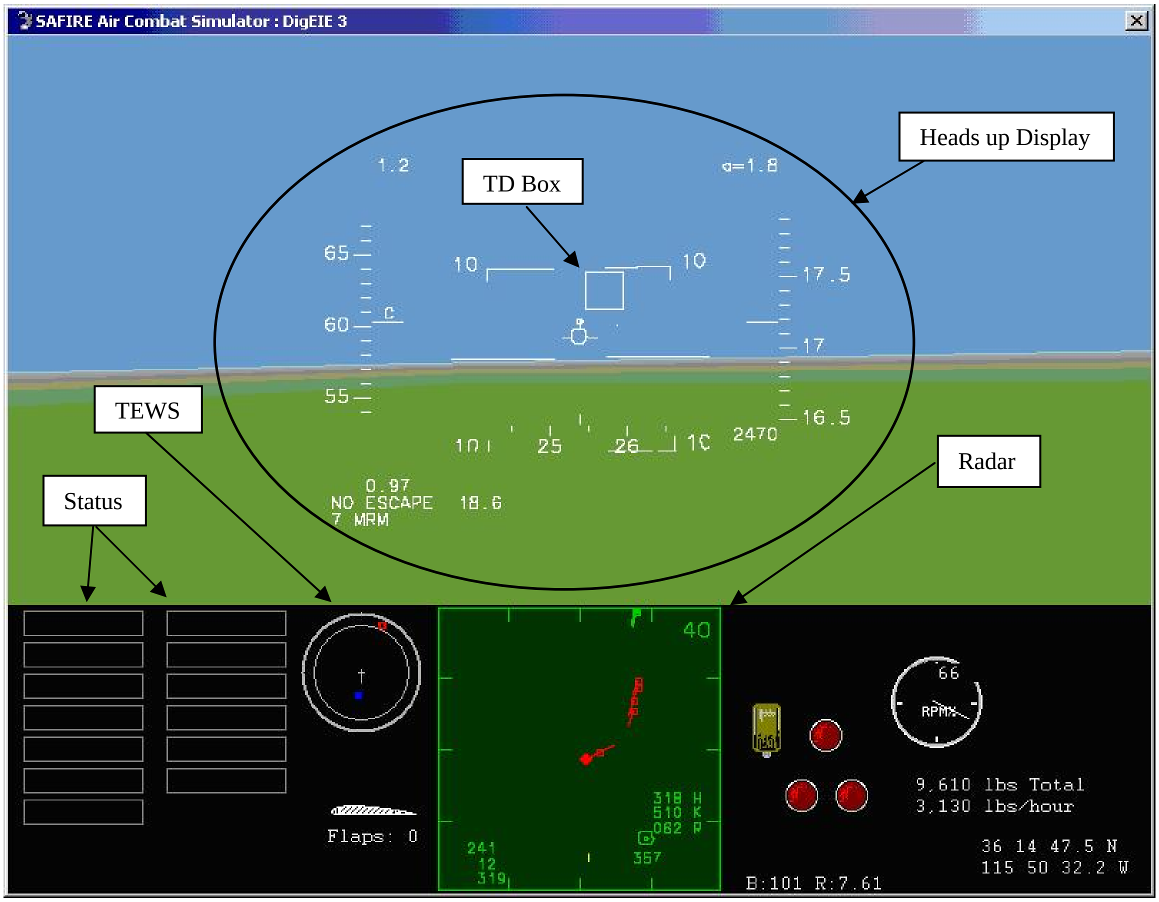


Figure 7. This is a screen capture from one of the blue fighter crew stations. The top portion of the display is the out-the-window scene with the HUD overlaid. The bottom section includes the radar display, the tactical electronic warning system (TEWS), engine, landing gear, flaps, and other status information. This screenshot was taken with the two blue aircraft in a lead-trail formation. The other blue aircraft can be seen on the TEWS display as a trailing blue dot. The red dot on the TEWS display indicates the direction of emissions from enemy aircraft.

The SAFIRE Air Combat Simulator (SACS) is an enhanced version of the desktop flight simulator software distributed by Web Simulations, Inc. The radar simulation (Figure 8) was modified to add roll and pitch stabilization. Radar emission information was constructed and broadcast using the Distributed Interactive Simulation (DIS) protocol. The SACS air-to-air missile capability was upgraded to include performance similar to the Advanced Medium Range Air-to-Air Missile (AMRAAM).

Blue Lead Aircraft's Radar **Blue Trailing Aircraft's Radar**

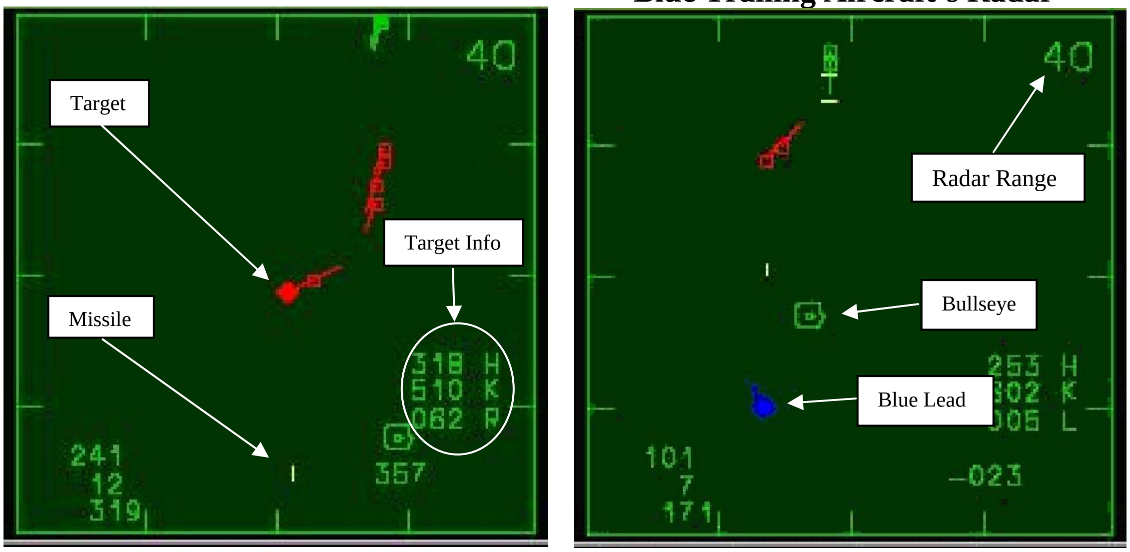


Figure 8. The two blue aircraft are in a lead-trail formation with a range split of approximately 10 nm. The blue lead has designated a target and fired a missile on it. The target information includes its heading, airspeed, and aspect angle. The numbers in the lower left are the targets range and bearing from the bullseye and its altitude. The trailing aircraft's radar, which includes the lead aircraft, illustrates the concept of mutual radar support.

The stick and throttle were programmed to allow control over aerodynamic features such as speed brakes, flaps, trim, and afterburner. A push-to-talk switch was implemented to allow keying of the microphone on the voice over IP radio software. For close-in air combat maneuvers, the controls could be used to fire guns. This caused a lead computing optical sight system (LCOSS) reticule to be activated on the heads-up display (HUD).

The ModIOS Voice Communicator software enables two way radio communications between the pilots and the airborne operator. This software uses the DIS standard to exchange data within a facility. When radio communications are required across facilities, the Network Interface Unit (NIU) software is used to implement the HLA multicast technique.

2.3 Blue Airborne Controller crew station

The Airborne Command and Control Operator, located in the Battlespace Visualization room (Figure 9), support the Blue fighters using the Virtual Battlespace Management System (VBMS) as a visualization tool (Figure 10). This tool simulates an airborne command and control display (such as an AWACS or E-2). The controller communicates with the Blue Team pilots using the simulated radio described earlier. A foot pedal switch was installed for the controller's push to talk device.

Figure 9. The battlespace visualization room housed the Virtual Battlespace Management System (VBMS). The Airborne Controller used this system to make broadcast calls and tactical calls for the read aircraft. The broadcast calls were made relative to the bullseye, and the tactical relative to the requesting blue aircraft. The Controller used a headset with boom microphone and used a push-to-talk switch located near his foot.

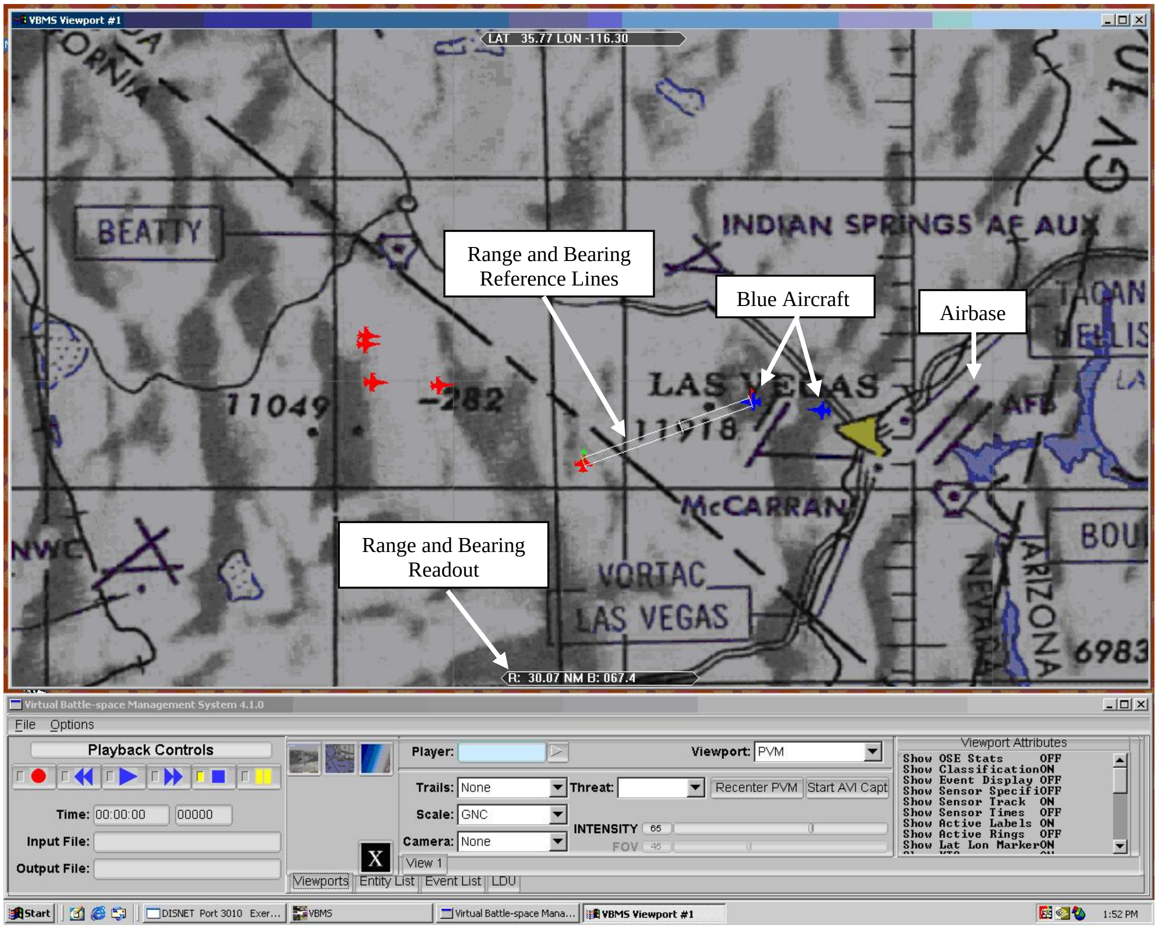


Figure 10. This is a screen capture from the Virtual Battlespace Management System (VBMS). This system was used by the airborne controller to make broadcast calls and tactical calls to the two blue pilots. In this scene, range and bearing is being measured from the lead blue aircraft and the closest enemy aircraft.

2.4 Red Team Aircraft

The Red Team bombers and fighters were provided and dynamically controlled using the Joint Simulated Automated Forces (JSAF) constructive simulation tool (Figure 11). This tool allows several scenarios to be created in advance and saved in files. Prior to each experimental run, a particular scenario is loaded and the red forces are authorized to prosecute the attack on the air base. Due to the complex nature of JSAF, the scenarios do no simply play out exactly the same way each time they are run. The JSAF entities dynamically respond to the actions of the blue pilots. This reactive nature allows for realistic, complex, and unique outcomes each time a scenario is executed.

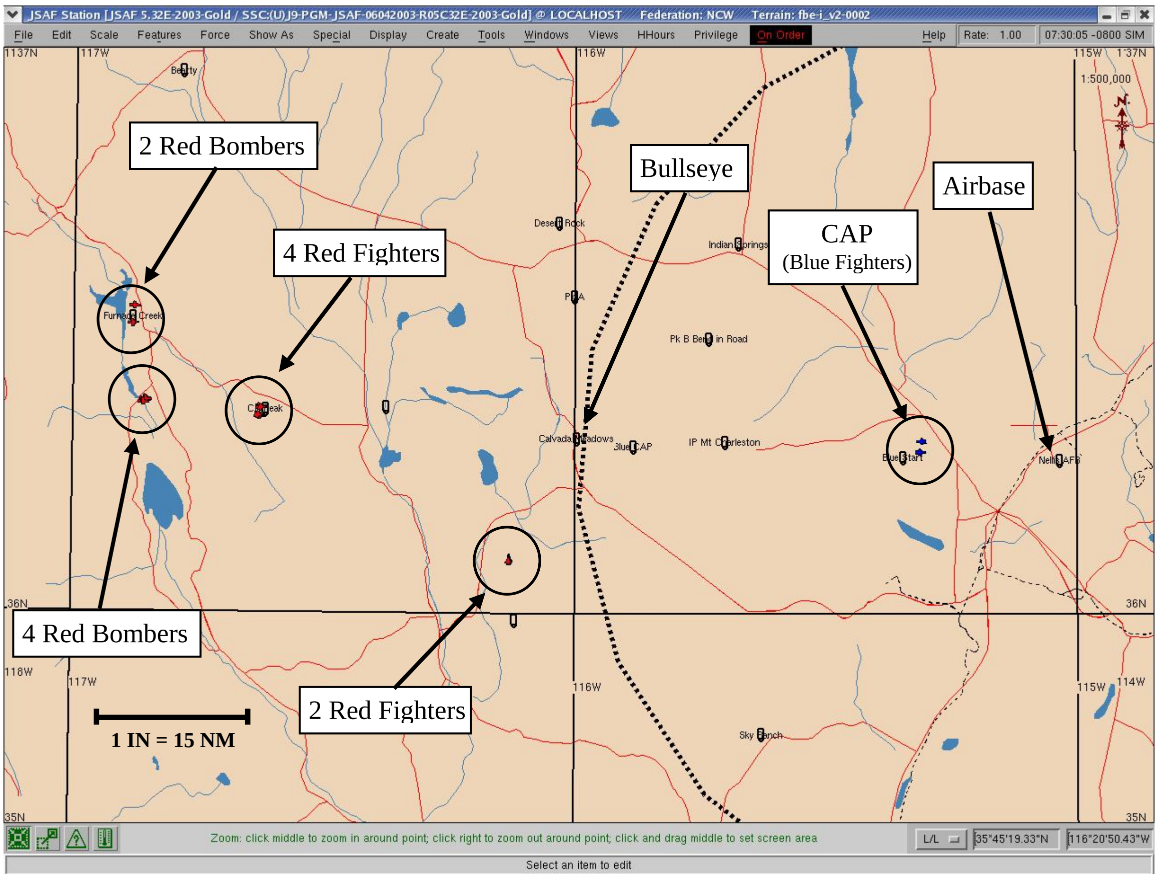


Figure 11. The JSAF constructive simulation tool is used to create scenarios for the red team and interactively execute their mission against the blue team The two blue fighters are in a CAP one mile apart with one heading east and one heading west.

The JSAF computer also contains a gateway that can perform translation between DIS and HLA constructs. This powerful feature means that the JSAF constructive simulation tool can be used in any node in the SAFIRE. In the current study, the JSAF station was located in the Battlespace Visualization room.

3. STUDY DESCRIPTION
3.1 Introduction

The Task: The two blue fighter pilots performed an airbase defense mission. The blue team's primary objective was to prevent the red attack aircraft from dropping any bombs on the airbase. Their secondary objective was to delay the dropping of the first bomb for as long a possible to allow ground assets on the runways to be moved. The blue pilot's primary source of information for all missions was the aircraft's attack radar system. The range of the radar system was experimentally controlled. A second source of information regarding the activity of the red aircraft is an airborne controller. The controller was present during one half of the missions.

Setup: At the beginning of each trial the two blue fighters were in a command air patrol (CAP) orbit 14 miles directly west of the air base. A bullseye was positioned 33 miles directly west of the blue aircraft's starting position. The bullseye position was shared between the two blue aircraft pilots and the airborne controller. The red aircraft would ingress from several positions west, north, and south of the bullseye. In each mission/trial there were six red fighters and six red attack (bomber) aircraft. Each blue aircraft was equipped with eight air-to-air missiles and 500 rounds of cannon fire

Experimental Hypothesis: The hypothesis of this study is that crew performance will be affected by information availability regarding the location and activity of the adversary aircraft, and, there will be an associated workload effect. There were two manipulations of Information availability. The first was accomplished by limiting the blue aircraft to three fixed radar ranges. The second was the presence, or lack of, communications with an airborne controller. It is further hypothesized that the crew performance effect will follow the Yerkes-Dodson Law, provided the information manipulations produce a workload effect.

3.2 Methods: Participants

Blue Team: Twelve air force lieutenants (13 male,1 female) volunteered for the study. All had normal, or corrected to normal, vision. The participants were grouped into pairs to form six blue teams. Each participant completed a signed consent form. The training and data collection took approximately 24 hours over a three month period.

Airborne Controller: One controller was utilized throughout the study. The controller was a trained E-2 controller with 1,000 hours of combat experience. The role of the controller was to provide information, relative to the red force formation and composition. The controller was strictly a source of information and was explicitly told not to direct the blue aircraft. The controller was unaware of the radar range settings for the blue aircraft. Generally, the controller would make broadcast calls (relative to bullseye), but when asked by the pilots for snap vectors, the controller would make tactical calls (relative to the aircraft).

3.3 Methods: Experimental Design

Independent Variables**:**

Radar Display Range (20, 40, and 80 nm)
Airborne Controller (Present vs. Not Present)

Dependent Variables**:**

Number of successful missions
Bombing delay
Number of bombers destroyed
Number of red fighters destroyed
Number of blue fighters lost
Workload
Situational awareness

For a mission to be successful, it meant that all of the red attack aircraft (bombers) were destroyed prior to dropping any bombs. It was possible to kill all of the red bombers and not prevent bombing of the airbase. This happened on at least one trial where an egressing bomber was shot down after releasing ordinance, and then an inbound bomber was destroyed.

The bombing delay was an important measure. The longer the bombers were delayed, the more time ground troops would have to move assets from the runways. A baseline delay was established by letting each scenario play out without the blue aircraft present. The bombing delay was measured as time beyond the baseline when the first bomb was released. The number of successful missions and the bombing delay are mutually exclusive measures.

Workload: The Subjective Workload Assessment Technique (SWAT) was used to collect subjective workload measures after each trial. Each participant received the SWAT training and performed the SWAT card sort prior to data collection.

Situational Awareness: The Situational Awareness Rating Technique (SART) was used to collect subjective situational awareness measures after each trial.

Scenarios: There were three different scenarios created for the red team using the JSAF constructive simulation tool. Each of these three scenarios contained the same number of fighter and attack aircraft with different starting positions. The three scenarios were not treated as an independent variable, but were implemented to prevent the pilot from learning a single scenario and thus predicting behavior.

The study utilized a within subject (team) design. The Presence of Controller variable was blocked. The order of Radar Range, Presence of Controller, and scenario were counterbalanced

3.4 Procedures: Trial Format

Prior to each data collection session, a checklist was followed to ensure that the pilot stations were calibrated correctly and that the radio communications were working properly. Each trial also had a set of procedures to follow to ensure that all tasks were accomplished in the correct order. The DIS Logger was started prior to each trial.

To begin the trial, the blue teams' fighter aircraft would be activated flying in the CAP with the predetermined radar range. At this time, the appropriate red team scenario would be started in the Battlespace Visualization Laboratory. If the block of trials included the airborne controller, he would use the Virtual Battlespace Management System (VBMS) and begin making "calls" when he saw that the red aircraft were present.

The two blue team pilots were instructed to remain in the CAP until they had a reason to leave it (i.e., they had an awareness of the red aircraft). This could happen in one of three ways. First, if there was an airborne controller he would alert the blue team when the red aircraft appeared on his screen. Second, one or more red aircraft would become visible on the blue team's radar, and third, one of the blue aircraft would get a spike on their defensive display from emissions by one of the Red aircraft. At this point the blue pilots would break out of the CAP and engage the adversaries.

The blue pilots were free to use tactics of their choice to perform the mission. The pilots were not told to use a specific tactic, nor were they directed to do so by the airborne controller. During the Advanced Tactics section of training regimen, the pilots were given the opportunity to practice several well defined tactics.

Each trial lasted approximately ten minutes. A trial was discontinued when one of the following criteria was met:

1) The mission was successful (all bombers were destroyed before dropping ordinance).
2) The first bomb had dropped on the runway and the blue team was no longer able to affect the outcome of the remaining bombers (e.g., both blue were dead or out of weapons).
3) All bombers had released their ordinance and were egressing.

A "knock if off" call was made when one of the above criteria were met. Mission outcome was scored manually during the trial and then verified in an after-action-review using the DIS Logs. Subjective measures were collected following each trial. The subjects were not given any specific feedback on their performance after the trial.

3.5 Procedures: Training

All of the eligible candidates who volunteered for the study had to progress through a highly structured training procedure. Participants where not allowed to advance to the next stage until they established competency in the current stage.

Basic Flying Skills: The basic flying skills portion of the training involved familiarization with the controls and displays of the simulation. Each participant was asked to fly at various altitudes, air speeds and headings; and to trim the aircraft at each condition.

Basic Targeting Skills: Once the participant displayed competency in flying the aircraft, then the concepts of the bullseye, radar operation, target designation and weapon delivery were introduced. This included recognizing changes to the radar symbology and the appearance of the target designator (TD) box on the HUD. To practice the switchology, the participants used a simple scenario with stationary targets.

Advanced Targeting Skills: The participants were introduced to the communications system (simulated radios with push-to-talk). The participants took turns at being the lead aircraft and being the wingman. When in the lead role, that participant would assign targets to the wingman using calls relative to the bullseye. The participants flew against a simple scenario where the red aircraft were live and had the ability to fire on the blue aircraft. In this phase of training the tactical electronic warning system (TEWS) was explained.

Communications: The subjects watched a video on Brevity given by an experienced controller. The AFTTP 3-1, Volume 1, Change 1, 2 Dec 1999 ATTACHMENT 1-1 OPERATIONAL BREVITY WORDS, TERMINOLOGY, and AIR-TO-AIR COMMUNICATION STANDARDS (U) was used as guidelines for the terminology Upon completion of the video, the participants were introduced to the Airborne Controller and flew against the Advance Targeting scenario while communicating with the controller. The correct use of terminology was reinforced throughout this phase.

Tactics: The participants watched a video presented by a retired fighter pilot (Shaw 1985) who addressed some basic tactics and defensive maneuvers. The video addressed strategies to maximize weapon effectiveness and how to defeat the opponents' weapons. After the video, the participants were briefed on the details of the airbase defense mission. They were also introduced to the CAP (Combat Air Patrol) concept. Following the discussion, the participants were given the opportunity to practice the tactics discussed in the video.

Advanced Tactics: The participants watched a brief video presented by an experienced fighter pilot who discussed maneuvering terminology and team oriented tactics. The participants then flew against practice scenarios and were given interactive tactical instruction. During this instruction the participants were given a specific tactic to try. The participants were then debriefed to discuss the pros and cons of the specific

tactic. In this session the participants completed the Subjective Workload Assessment Technique (SWAT) card sort. The specific tactics were:

1) **Guard home plate and the bullseye**: The two blue aircraft would split up with one going back to the airbase and circling the runway waiting for red aircraft to come into its radar range. The other blue aircraft would fly west to the bullseye and maintain a CAP-like orbit until it could engage the bandits. This is a conservative tactic that teaches patience.
2) **Engage and guard home plate**: Similar to the above except the second blue aircraft doesn't stop at the bullseye. It keeps flying west searching for the adversary. This tactic illustrates the dangers of engaging the enemies as a single ship while demonstrating the importance of preventing "leakers" from slipping through to bomb the base.
3) **Both Engage**: With this tactic both blue aircraft immediately fly west in an abreast formation to search out and engage the enemy as far from the airbase as possible. This tactic allows the participants to practice evasive maneuvers and the highlights possible advantages of being very aggressive.
4) **CAP-like shoot-and-turn**: Both blue aircraft begin flying west with a range split of approximately 15 nm. When the lead aircraft is within weapon range, he shoots and turns east, eventually passing by the other blue aircraft, which then becomes the lead. This aircraft then shoots and turns, and the pattern repeats. This tactic illustrates the concept of mutual radar support.
5) **North-South azimuth split**. The two blue aircraft split with one flying southwest and one flying northwest until they are 30-40 nm apart. They then engage separate enemies that they encounter. This tactic avoids the pitfalls of the fly straight in and engages tactics, which can lead to a red team trap (i.e., ambush). Additionally it illustrates the advantage of spreading out the radar coverage to prevent red attack aircraft from slipping around the flanks and attacking the airbase.
6) **High-Low elevation split**: One blue aircraft would fly directly west at low altitude (10K feet) and the other would fly west while climbing to a high altitude (40K feet) and substantially increase airspeed. This tactic emphasizes the advantage of having a high-energy weapon release condition. It also illustrates the method to increase radar coverage in the vertical dimension.

3.6 Procedures: Team Formation and Practice

Based on availability and progress through the training regimen, participants were paired to form a team. Once a team was established, they were given the opportunity to practice with and without the controller. During these practice sessions the necessity of tactics was continually reinforced. The participants were not limited to the tactics taught in the Advanced Tactics phase of training. They could use a combination of those tactics or develop and practice new ones. However, it was strongly emphasized that when a trial begins, the team must have decided on a tactic and it must be clearly communicated. The team remained in the practice phase of

training until they achieved 50% success against the practice scenarios. At that point they proceeded to the Mission Rehearsal phase.

3.7 Procedures: Mission Rehearsal

During mission rehearsal the participants flew against even harder scenarios with all the conditions (20, 40, 80 mile radar range, with and without a controller). Subjective workload and situational awareness measures (SART and SWAT) were taken after each trial. The participants were allowed to ask questions during mission rehearsal, but minimal guidance was provided.

3.8 Procedures: Data Collection

Prior to data collection the participants were given a written set of instructions (Appendix B) to read and any remaining questions were answered. During the data collection trials no guidance was provided by the experimenters. The participants had to rely on their training, communication with each other, and communication with the Airborne Controller, if present.

Three new red team scenarios (Appendix A) were created using the JSAF constructive simulation tool. These scenarios were more difficult that the ones used in the mission rehearsal stage of training. Data collection consisted of a total of 18 trials (three scenarios, three radar ranges, and Airborne Controller present or absent). Typically the 18 trials were completed in two sessions on two separate days. However, this was not always possible do to the military commitments of the participants.

4. RESULTS

Data representing 8 dependent variables (6 objective and 2 subjective) were collected from 7 teams of participants. The data were collected during trials in which two independent variables were systematically manipulated. Data were averaged across the three scenarios for each team and treatment combination.

4.1 Definition of Variables

Names of the dependent and independent variables, along with their associated descriptions, are shown in Table 2 below.

Variable Name	Variable Description	Type
Success	Percentage of successful missions(no bombs detonated on airbase)	Dependent
Delay	Difference between baseline time of scenario and time from scenario start to first bomb detonation on airbase	Dependent
Bombers	Number of adversary bombers shot down in a single mission	Dependent
Escorts	Number of adversary fighters shot down in a single mission	Dependent
Bandits	Number of adversary aircraft(fighters and bombers) shot down in a single mission	Dependent
Fighters	Number of friendly fighters shot down	Dependent
Workload	Subjective workload measured using the SWAT methodology	Dependent
SA	Situation Awareness measured using the SART methodology	Dependent
Range	Range of radar display in friendly fighter simulations	Independent
Controller	Availability of friendly airborne controller	Independent

4.2 Primary Graphical Results

Data collected during this study representing the dependent variables as a function of the independent variables is depicted graphically in Figures 12 through 19 below.

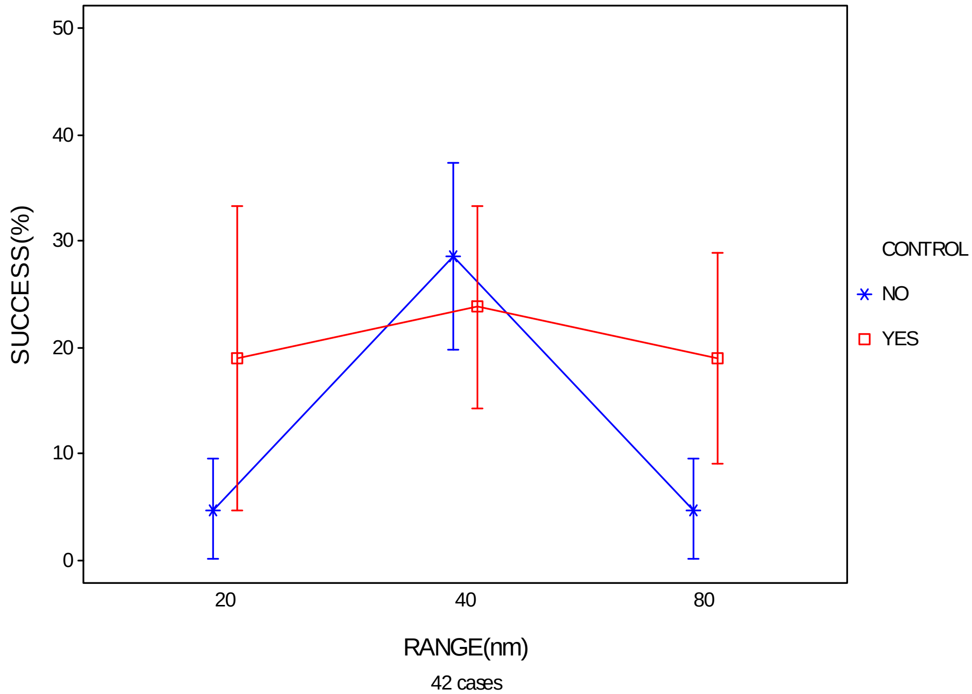


Figure 12 - **Percentage of Successful Missions.**

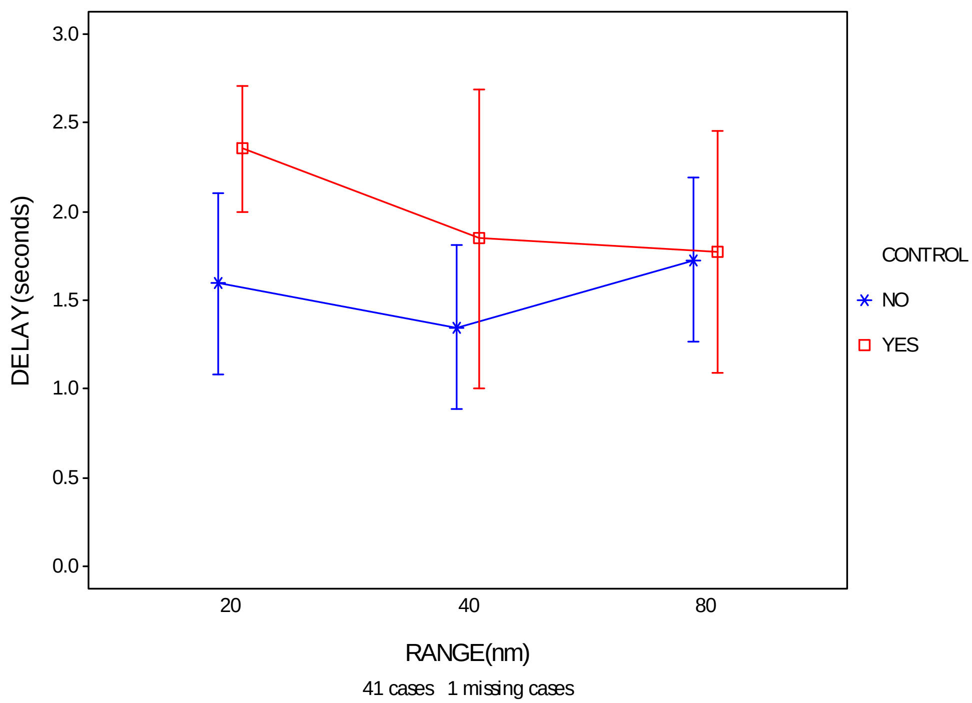


Figure 13 - **Average Bombing Delay per Mission.**

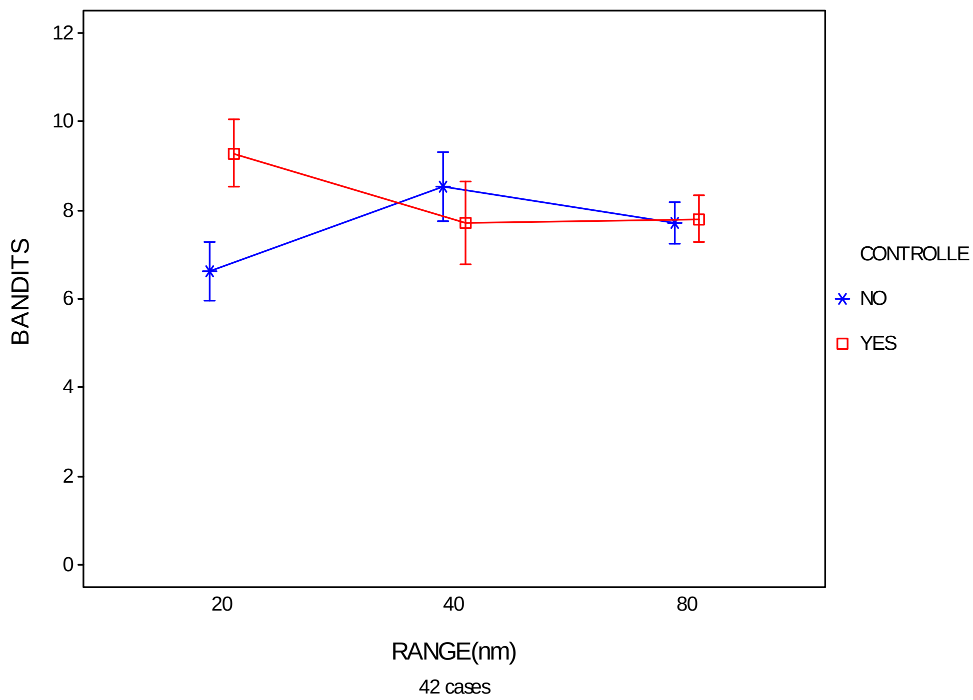


Figure 14 - **Average Number of Bandits Shot Down per Mission.**

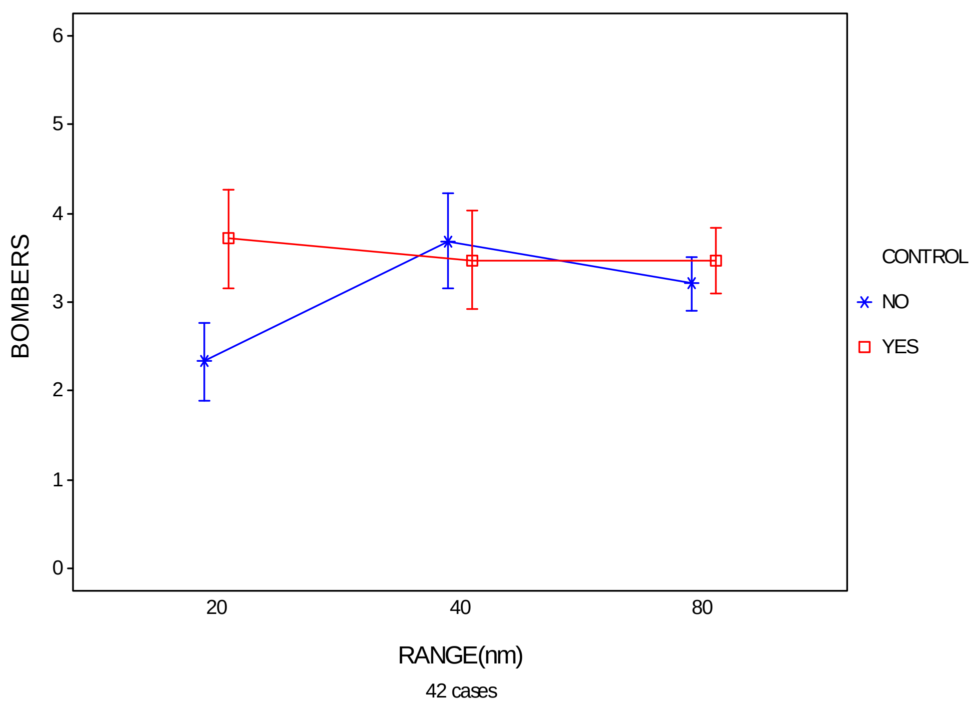


Figure 15 - **Average Number of Bombers Shot Down per Mission.**

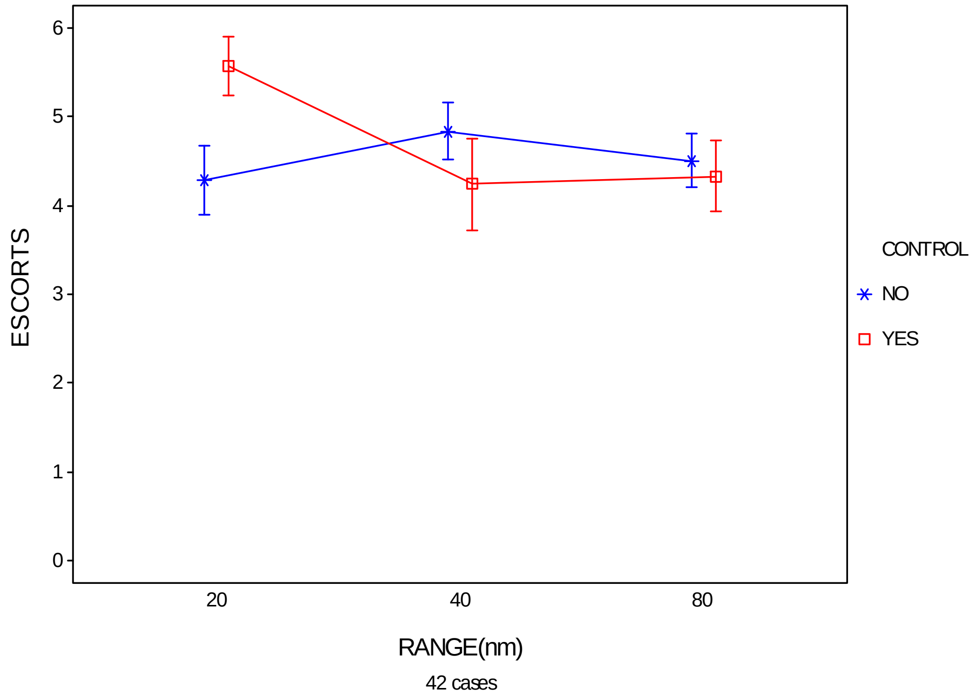


Figure 16 - **Average Number of Escorts Shot Down per Mission.**

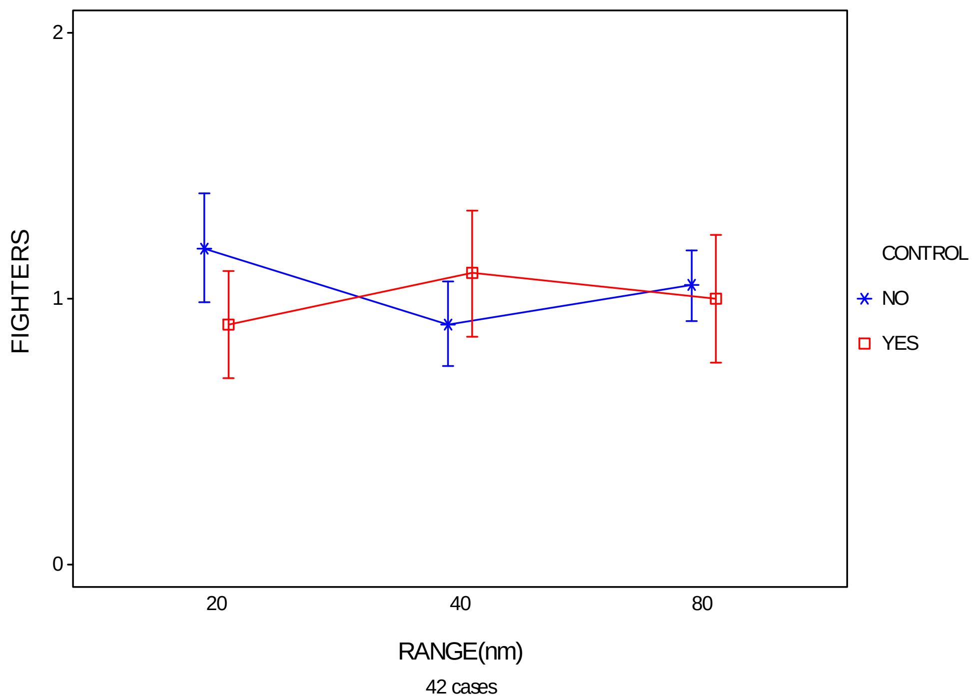


Figure 17 - **Average Number of Friendly Fighters Lost per Mission.**

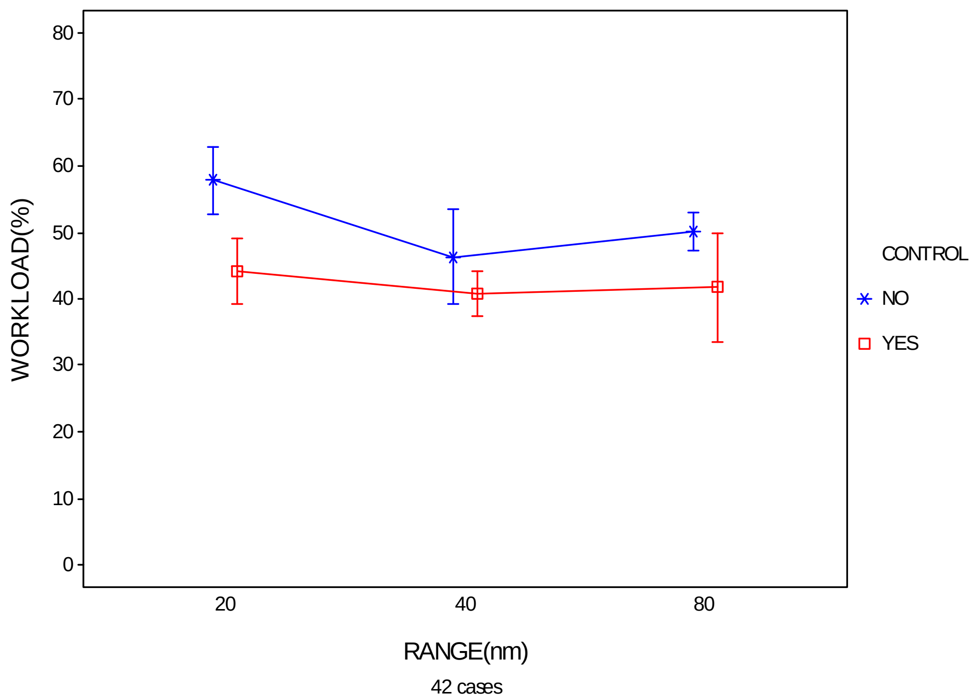


Figure 18 - **Average Team Subjective Workload per Mission.**

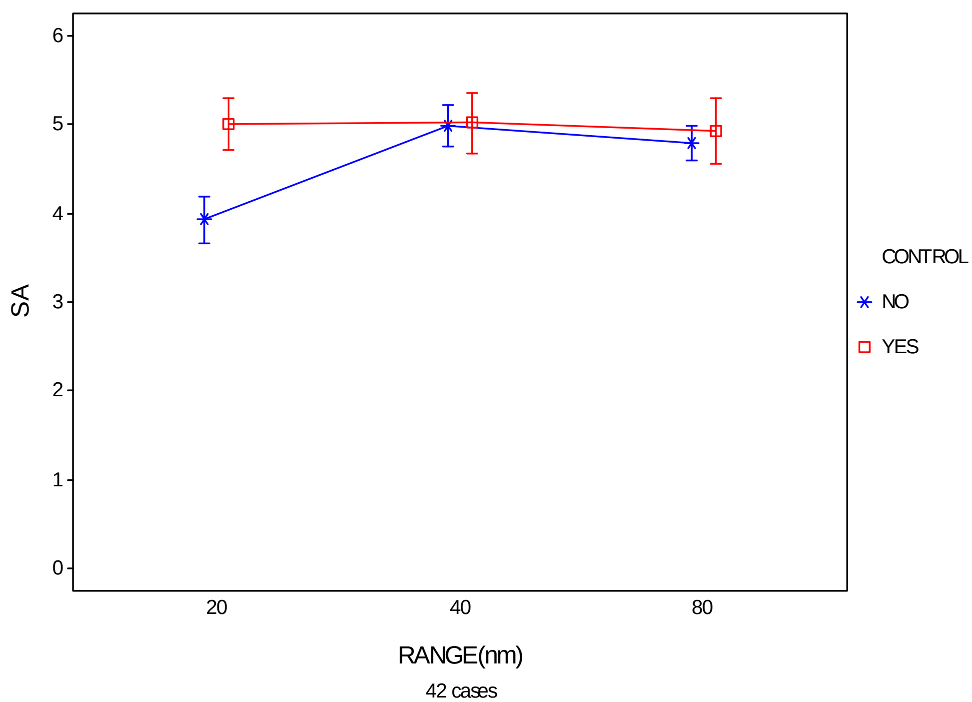


Figure 19 - **Average Team Situation Awareness per Mission.**

4.3 Primary ANOVA Results

Although many of these figures resemble the Yerkes-Dodson curve, and thus support the experimental hypothesis, a statistical analysis of the data must be completed before reliable conclusions can be drawn.

Eight two-way analyses of variance were performed on the collected data. The analyses of variance indicated that the two independent variables interacted to significantly affect the number of bandits shot down ($F=6.24(2,12)$,($p < .05$), the number of escorts shot down ($F = 10.58(2,12)$, $p < .05$) and Situation Awareness ($F = 9.56(2,12)$, $p < .05$). The results of eight two-way analyses of variance of the objective and subjective dependent variables are shown below. It should be noted that the missing data in the analysis of Delay was attributable to all missions in that particular cell were successful (no bombs were dropped on the airbase and thus the variable Delay was indeterminate.

ANALYSIS OF VARIANCE TABLE FOR SUCCESS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	0.48148	0.08025		
CONTROLLER (B)	1	0.06614	0.06614	1.23	0.3100
A*B	6	0.32275	0.05379		
RANGE (C)	2	0.19048	0.09524	1.48	0.2665
A*C	12	0.77249	0.06437		
B*C	2	0.08466	0.04233	0.87	0.4427
A*B*C	12	0.58201	0.04850		
TOTAL	41	2.50000			

ANALYSIS OF VARIANCE TABLE FOR DELAY

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	20.5299	3.42164	2.04	0.2028
CONTROLLER (B)	1	1.96401	1.96401	1.17	0.3203
A*B	6	10.0428	1.67380		
RANGE (C)	2	0.97699	0.48849	0.21	0.8107
A*C	12	27.4512	2.28760		
B*C	2	0.88566	0.44283	0.20	0.8193
A*B*C	11	24.0049	2.18227		
TOTAL	40	85.8555			

CASES INCLUDED 41   MISSING CASES 1

CAUTION: The sums of squares, mean squares, and F-tests are approximate for analyses with missing values. See the manual for details and instructions for constructing exact F-tests.

ANALYSIS OF VARIANCE TABLE FOR BANDITS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	27.4527	4.57545		
RANGE (B)	2	0.89616	0.44808	0.16	0.8543
A*B	12	33.6941	2.80784		
CONTROLLER (C)	1	4.45399	4.45399	0.64	0.4540
A*C	6	41.7198	6.95329		
B*C	2	22.7589	11.3795	6.24	0.0139
A*B*C	12	21.8989	1.82491		
TOTAL	41	152.875			

ANALYSIS OF VARIANCE TABLE FOR BOMBERS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	15.1480	2.52467		
CONTROLLER (B)	1	2.43372	2.43372	1.09	0.3367
A*B	6	13.3954	2.23256		
RANGE (C)	2	2.17650	1.08825	1.17	0.3426
A*C	12	11.1353	0.92794		
B*C	2	4.64578	2.32289	1.77	0.2126
A*B*C	12	15.7801	1.31501		
TOTAL	41	64.7148			

ANALYSIS OF VARIANCE TABLE FOR ESCORTS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	4.03238	0.67206		
CONTROLLER (B)	1	0.30295	0.30295	0.14	0.7213
A*B	6	12.9952	2.16587		
RANGE (C)	2	1.97945	0.98972	0.73	0.5010
A*C	12	16.2112	1.35093		
B*C	2	6.85856	3.42928	10.58	0.0022
A*B*C	12	3.89074	0.32423		
TOTAL	41	46.2705			

ANALYSIS OF VARIANCE TABLE FOR FIGHTERS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	2.07702	0.34617		
CONTROLLER (B)	1	0.02445	0.02445	0.04	0.8407
A*B	6	3.32744	0.55457		
RANGE (C)	2	0.01562	0.00781	0.05	0.9531
A*C	12	1.94383	0.16199		
B*C	2	0.39557	0.19778	0.86	0.4461
A*B*C	12	2.74728	0.22894		
TOTAL	41	10.5312			

ANALYSIS OF VARIANCE TABLE FOR WORKLOAD

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	2158.87	359.812		
CONTROLLER (B)	1	886.249	886.249	2.94	0.1371
A*B	6	1807.46	301.244		
RANGE (C)	2	401.545	200.773	2.07	0.1689
A*C	12	1163.72	96.9767		
B*C	2	120.455	60.2275	0.27	0.7706
A*B*C	12	2714.23	226.186		
TOTAL	41	9252.54			

ANALYSIS OF VARIANCE TABLE FOR SA

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	9.19108	1.53185		
CONTROLLER (B)	1	1.77988	1.77988	2.39	0.1729
A*B	6	4.46471	0.74412		
RANGE (C)	2	2.21284	1.10642	2.19	0.1551
A*C	12	6.07437	0.50620		
B*C	2	2.30067	1.15033	9.56	0.0033
A*B*C	12	1.44448	0.12037		
TOTAL	41	27.4680			

4.4 Secondary Analyses: Effects of Stage

A two-factor within-subjects design was utilized in this study with resulting data being averaged across three scenarios for each combination of team and treatment condition. While not a repeated measures design by rigorous definition, data resulting from the utilization of the three scenarios could be viewed as three repeated measures. Additionally, there were several tactics that may have been employed by the participants while attempting to defend the airbase and those tactics may have been changing throughout the data collection period. Many of these tactics were presented to, and practiced by, the participants during their training. The selection of tactics was not constrained during data collection. The scenarios utilized during data collection were different than those used during training. The combination of these elements makes it essential to analyze the data for the potential existence of “practice effects”, effects embedded in the data resulting from the adaptation of the participants to the experimental conditions.

Shaughnessy and Zechmeister(Shaughnessy, 1990) recommend separate statistical analyses for practice effects and for independent variable effects. A variable must be introduced to perform the separate analysis representing the sequential order of the independent variable presentations. Although arbitrary, the most straight-forward approach to create this new variable from this dataset was to break the data from each team into the two blocks associated with the presence or absence of the controller. Stage was introduced into the dataset as the new variable with a value of 1 representing the first 9 trials of each team and the value 2 representing the last 9 trials from each team. Of the 7 teams, 3 teams had the controller present in Stage 1 and 4 teams had the controller present in Stage 2. To statistically evaluate if “practice effects” may have

been present in the dataset, two dependent variables previously determined not to have been significantly affected by the independent variables were analyzed using State as a within-subject independent variable. These analyses revealed that both the number of bombers shot down (Bombers) and subjective workload (Workload), were significantly affected by Stage ($F = 4.58(1,6)$, $p < .05$ and $F = 6.08(1,6)$, $p < .05$ respectively). Graphical depictions, as well as results of the analyses of variance are shown below.

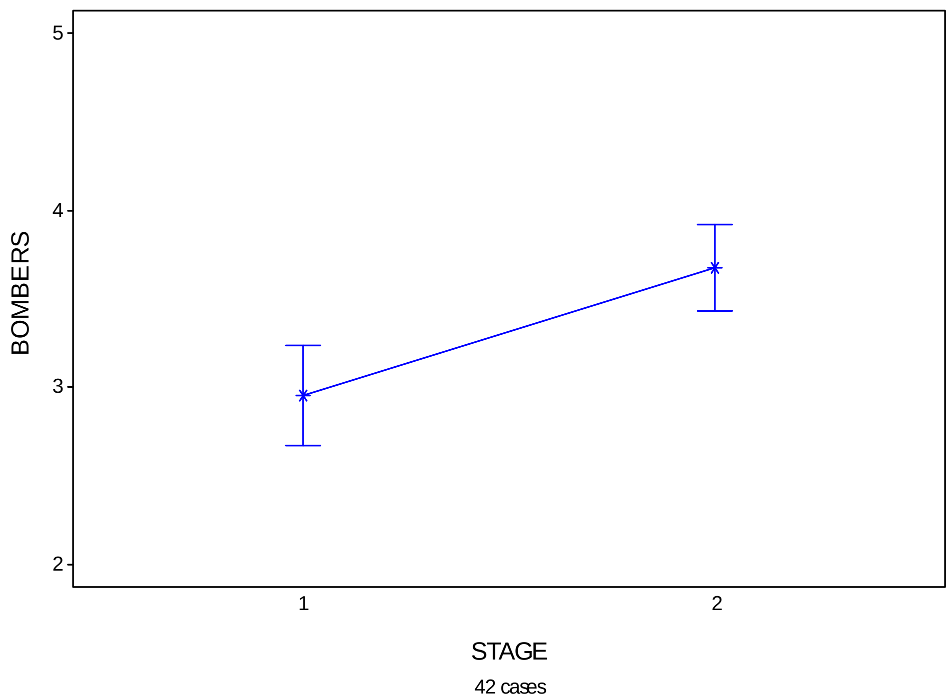


Figure 20 - **Number of Bombers Shot Down as a Function of Stage.**

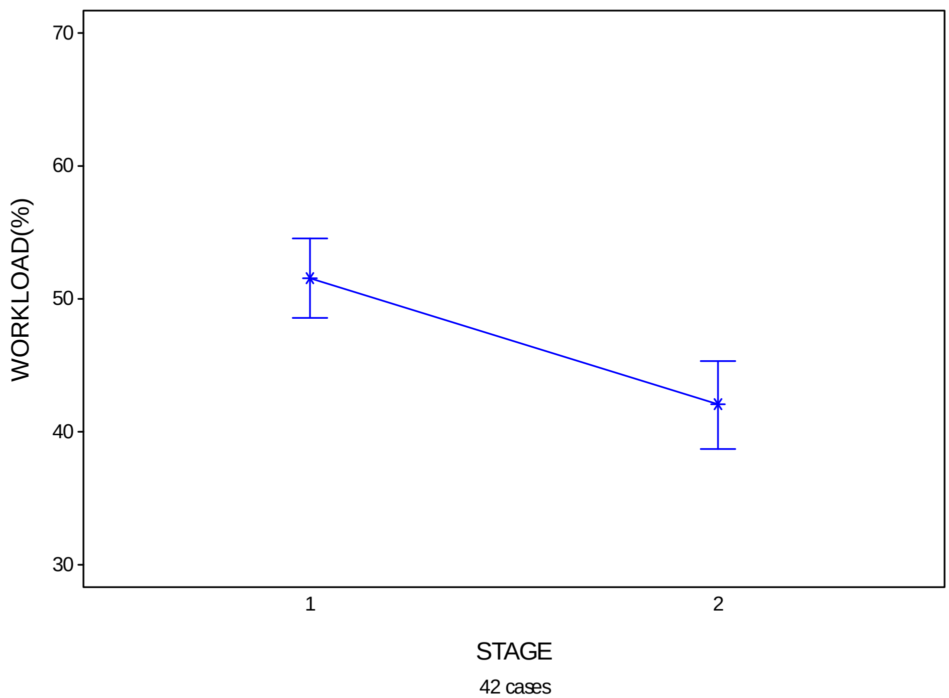


Figure 21 - **Subjective Workload as a Function of Stage.**

ANALYSIS OF VARIANCE TABLE FOR BOMBERS

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	15.1480	2.52467		
STAGE (B)	1	5.51770	5.51770	4.58	0.0412
A*B	6	10.3114	1.71856	1.43	0.2398
RESIDUAL	28	33.7377	1.20492		
TOTAL	41	64.7148			

ANALYSIS OF VARIANCE TABLE FOR WORKLOAD

SOURCE	DF	SS	MS	F	P
TEAM (A)	6	2158.87	359.812		
STAGE (B)	1	955.897	955.897	6.08	0.0200
A*B	6	1737.82	289.636	1.84	0.1267
RESIDUAL	28	4399.95	157.141		
TOTAL	41	9252.54			

4.5 Secondary Analyses: Graphs and ANOVAs

The clear statistical indications of “practice effects” in the dataset compel an additional analysis of the data from only Stage 2. However, this secondary analysis using only Stage 2 data must be performed with the independent variable Controller being treated as a between-subject manipulation and the independent variable Range treated as a within-subject manipulation. In essence, the dataset must be analyzed as a mixed two factor design and is complicated by differing numbers of teams in the two levels of the Controller variable.

Graphs of the eight dependent variables are shown below.

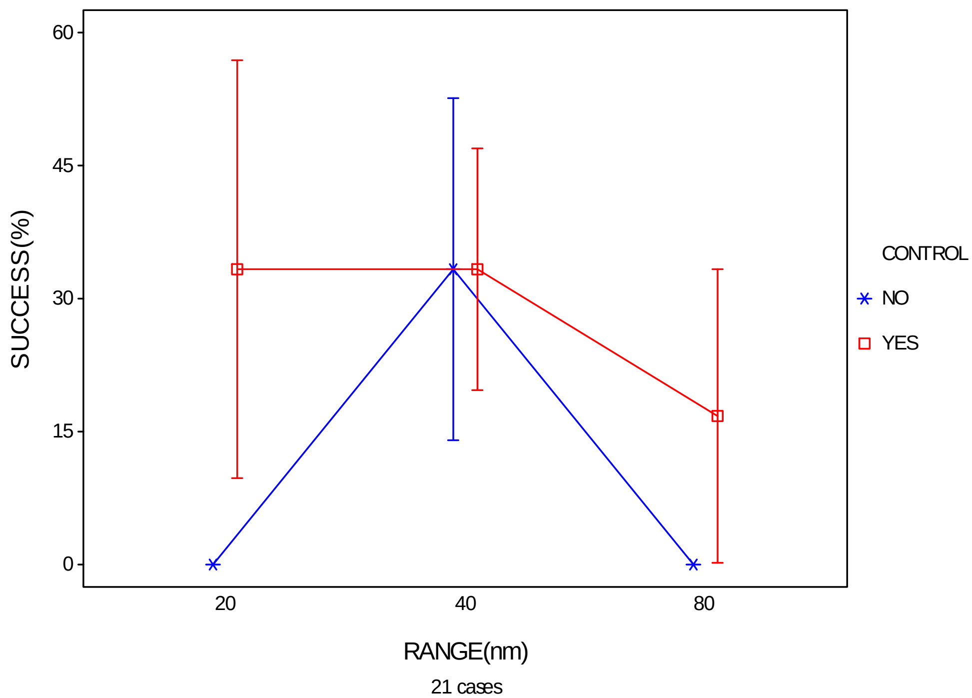


Figure 22 - **Percentage of Successful Missions.**

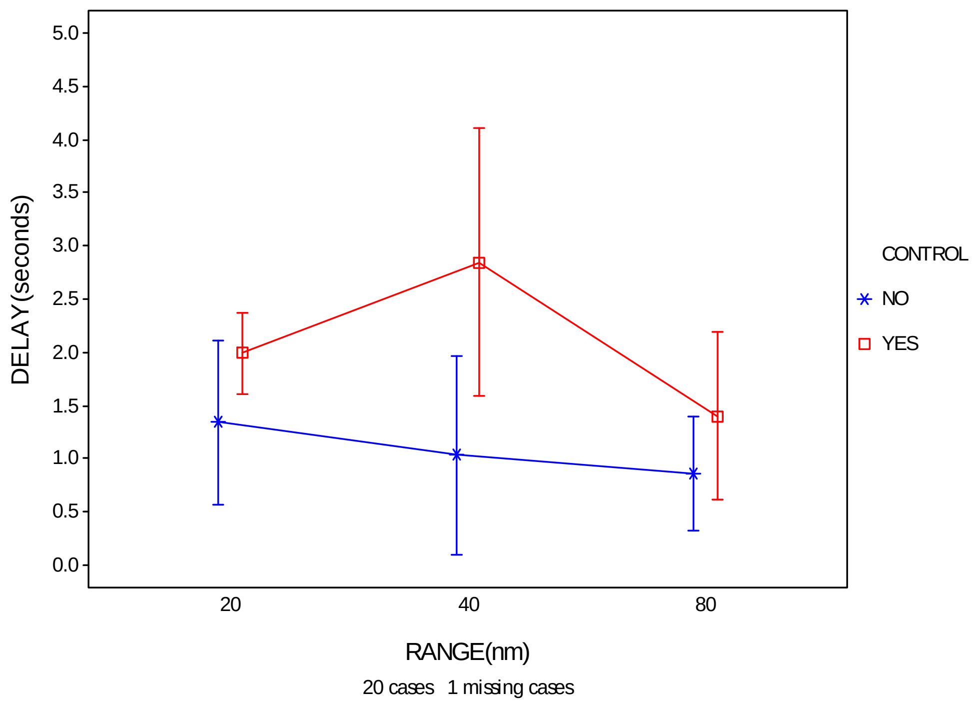


Figure 23 - **Average Bombing Delay per Mission.**

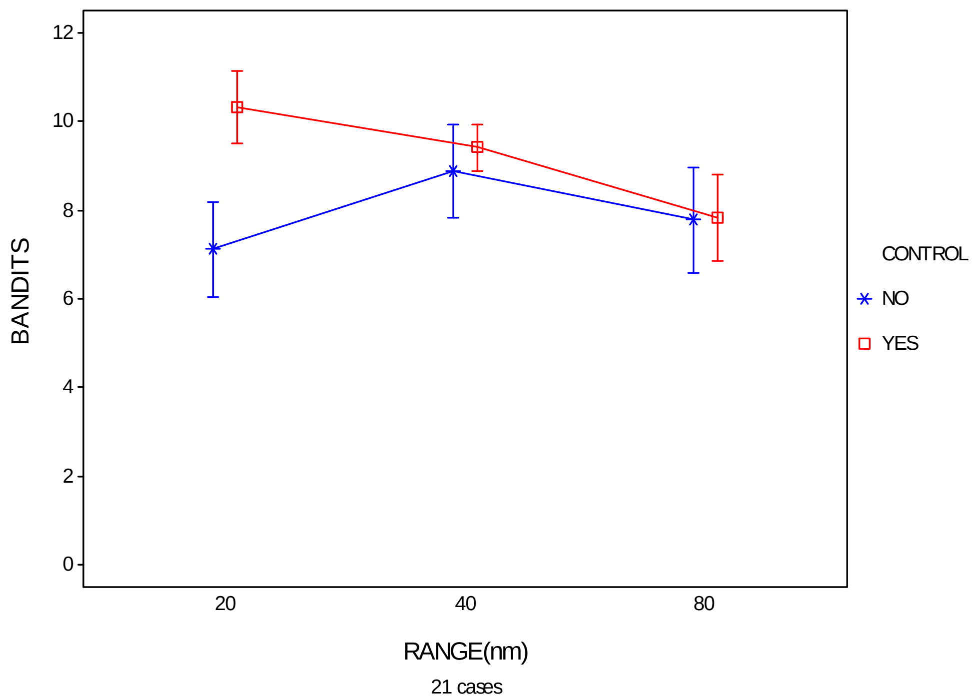


Figure 24 - **Average Number of Bandits Shot Down per Mission.**

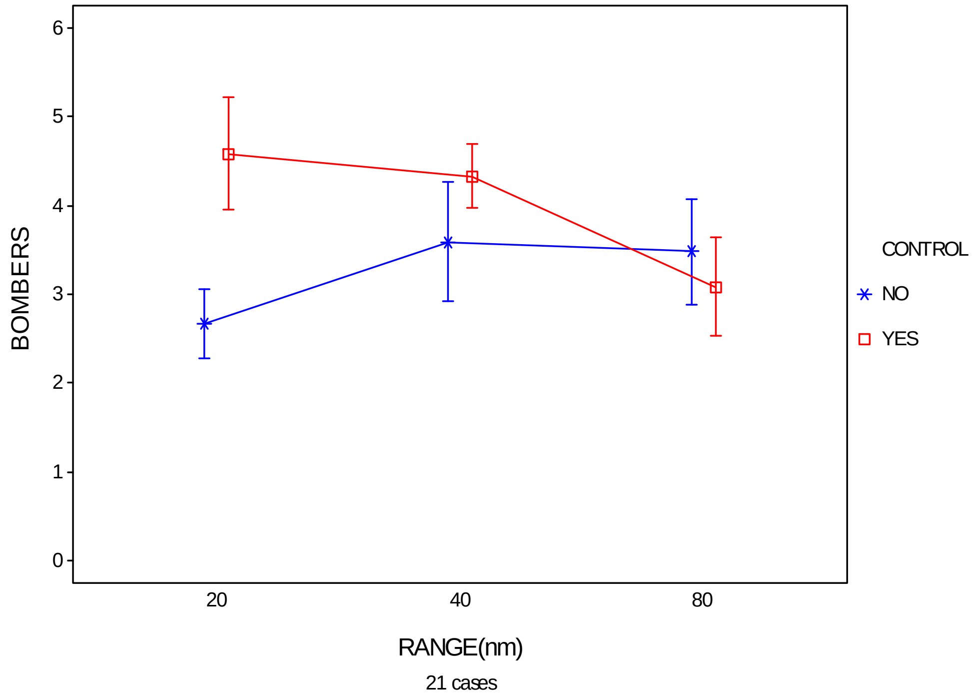


Figure 25 - **Average Number of Bombers Shot Down per Mission.**

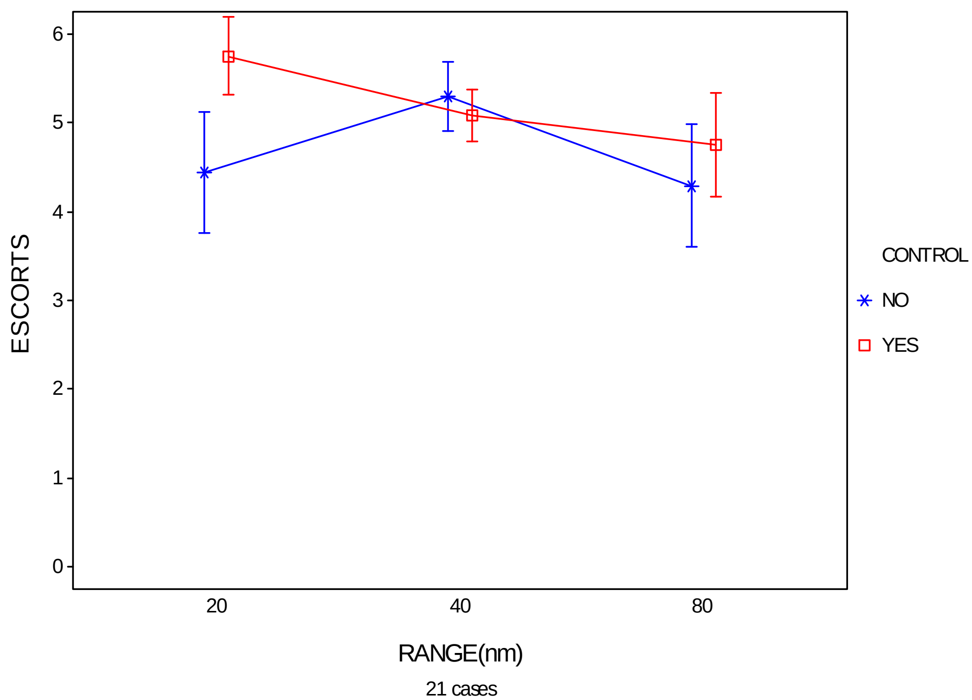


Figure 26 - **Average Number of Escorts Shot Down per Mission.**

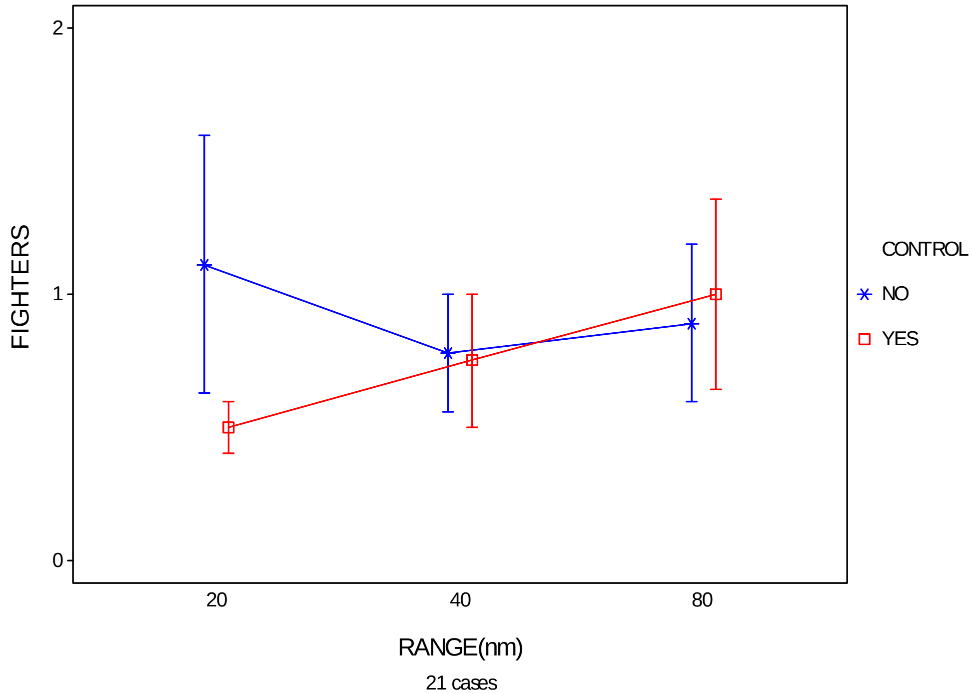


Figure 27 - **Average Number of Friendly Fighters Lost per Mission.**

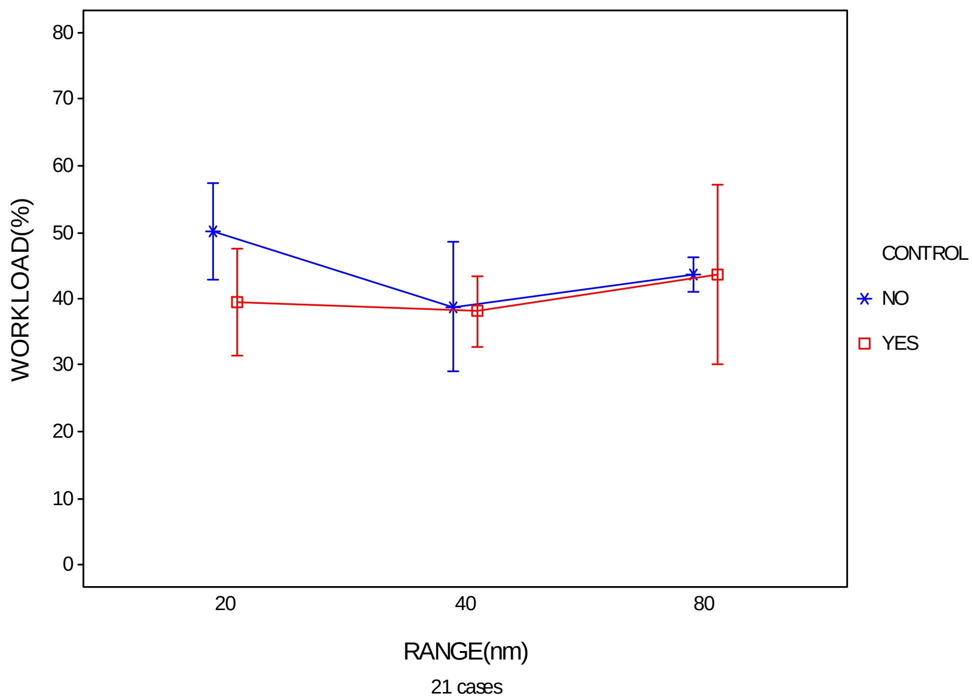


Figure 28 - **Average Team Subjective Workload per Mission.**

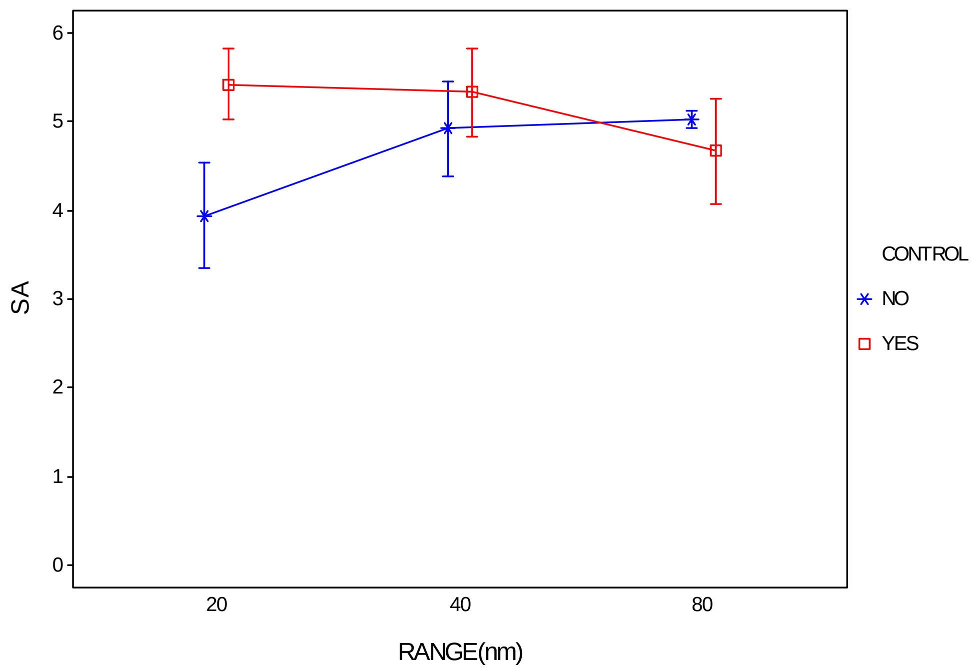


Figure 29 - **Average Team Situation Awareness per Mission.**

The results of the secondary statistical analyses indicated that SA was significantly affected by the interaction of radar range (Radar) and the presence of the controller(Controller) (F=4.607(2,10), p < .05). The results of the eight secondary statistical analyses are shown below.

Dep Var: SUCCESS N: 21 Multiple R: 1.000 Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
RANGE	2222.095	2	1111.048	1.250	0.328
CONTROLLER$	1428.524	1	1428.524	1.286	0.308
CONTROLLER$*RANGE	952.381	2	476.190	0.536	0.601
TEAM(CONTROLLER$)	5555.889	5	1111.178	.	.
RANGE*TEAM(CONTROLLER$)	8889.333	10	888.933	.	.
Error	0.000	0	.		

Dep Var: DELAY N: 21 Note: 1 Missing value

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
RANGE	2.252	1	2.252	0.958	0.351
CONTROLLER$	2.871	1	2.871	1.227	0.318
CONTROLLER$*RANGE	1.706	2	0.853	0.363	0.704
TEAM(CONTROLLER$)	11.702	5	2.340	.	.
RANGE*TEAM(CONTROLLER$)	23.494	10	2.349	.	.
Error	0.000	0	.		

Dep Var: BOMBERS   N: 21   Multiple R: 1.000   Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	1.593	2	0.797	0.933	0.425	.	.
CONTROLLER$	2.912	1	2.912	2.021	0.214	.	.
CONTROLLER$*RANGE	4.587	2	2.294	2.686	0.116	.	.
TEAM(CONTROLLER$)	7.206	5	1.441	.	.		
RANGE*TEAM(CONTROLLER$)	8.539	10	0.854	.	.		
Error	0.000	0	.				

Dep Var: ESCORTS   N: 21   Multiple R: 1.000   Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	1.793	2	0.896	1.016	0.397	.	.
CONTROLLER$	1.361	1	1.361	1.355	0.297	.	.
CONTROLLER$*RANGE	1.993	2	0.996	1.129	0.361	.	.
TEAM(CONTROLLER$)	5.023	5	1.005	.	.		
RANGE*TEAM(CONTROLLER$)	8.822	10	0.882	.	.		
Error	0.000	0	.				

Dep Var: FIGHTERS   N: 21   Multiple R: 1.000   Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	0.124	2	0.062	0.301	0.747	.	.
CONTROLLER$	0.162	1	0.162	0.311	0.601	.	.
CONTROLLER$*RANGE	0.498	2	0.249	1.212	0.338	.	.
TEAM(CONTROLLER$)	2.606	5	0.521	.	.		
RANGE*TEAM(CONTROLLER$)	2.057	10	0.206	.	.		
Error	0.000	0	.				

Dep Var: BANDITS   N: 21   Multiple R: 1.000   Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	6.509	2	3.254	1.156	0.354	.	.
CONTROLLER$	8.277	1	8.277	2.502	0.175	.	.
CONTROLLER$*RANGE	10.008	2	5.004	1.777	0.219	.	.
TEAM(CONTROLLER$)	16.540	5	3.308	.	.		
RANGE*TEAM(CONTROLLER$)	28.155	10	2.816	.	.		
Error	0.000	0	.				

Dep Var: WORKLOAD N: 21 Multiple R: 1.000 Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	159.491	2	79.746	0.490	0.627	.	.
CONTROLLER$	71.990	1	71.990	0.137	0.727	.	.
CONTROLLER$*RANGE	120.730	2	60.365	0.371	0.699	.	.
TEAM(CONTROLLER$)	2629.756	5	525.951	.	.		
RANGE*TEAM(CONTROLLER$)	1628.006	10	162.801	.	.		
Error	0.000	0	.				

Dep Var: SA N: 21 Multiple R: 1.000 Squared multiple R: 1.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P		
RANGE	0.699	2	0.350	1.105	0.368	.	.
CONTROLLER$	1.332	1	1.332	0.675	0.449	.	.
CONTROLLER$*RANGE	2.914	2	1.457	4.607	0.038	.	.
TEAM(CONTROLLER$)	9.865	5	1.973	.	.		
RANGE*TEAM(CONTROLLER$)	3.163	10	0.316	.	.		
Error	0.000	0	.				

5. DISCUSSION AND CONCLUSIONS

Albert's model of network centric operations portrays a sequence of effects beginning with information availability affecting situation awareness which in turn affects task performance. The statistically significant interactions found in this study of radar range and the presence of the controller on the situation awareness of the simulation pilots and on the number of bandits shot down supports the constructs of this model. In addition, the reduction in situation awareness in the 20 nm range without the controller relative to the other radar ranges, partially supports the presence of a "Yerkes-Dodson curve" to the shape of the data. The lack of statistically significant reductions at the 80 nm range and the lack of increases in situation awareness, workload, and performance when the controller was present do not support the presence of a "Yerkes-Dodson curve" shape to the data.

The statistically significant difference in performance and workload observed between the first and last halves of trials was quite unexpected. It is not clear from the data the cause of these shifts. One plausible explanation may have been that the participants became increasingly familiar with the actions of the adversary aircraft and their pre-planned flight paths. Alternatively, the shifts may have been due to optimization of tactics utilized. Because no constraints were imposed on the participants in terms of choice of tactics, the same three scenarios being used the same number of times in both trial periods, and there typically being a significant time gap between the first and last half of data collection periods, the participants may have chosen what they considered to be "the best" tactic and repeatedly used it during the second half of the trials. This issue should be addressed in future studies to determine

the cause of this shift and, in turn, to better control its effects in future studies having similar characteristics to this study.

The secondary analysis which involved analyzing only data from the second half of the trials revealed a similar interaction on situation awareness but the significant interaction observed in performance was no longer present. It is difficult to draw reliable conclusions from these data in that for each combination of independent variable level, only 3 or 4 data points are present and that the unbalanced nature of the data requires the analysis of variance to be estimated. With this in mind, it could be speculated that the reduction in power of the secondary analyses had masked observable effects. This speculation is somewhat substantiated by inspection of the graphical portrayal of the data and the similar nature of the trends in the means.

One overall conclusion to be drawn from the description of the SAFIRE and the results of this initial study is that the SAFIRE is capable of hosting evaluations of NCW interface concepts and that there is a need to further understand the implications of information characteristics in the design of crew interfaces to be used in network-centric operation.

6. REFERENCES

Taylor, R.M. (1990). Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In *Situational Awareness in Aerospace Operations* (AGARD-CP-478, pp. 3-1 and 3-17). Neuilly Sur Seine, France: NATO-AGARD.

Alberts, D.S., Garstka, J.J., and Stein, F.P. (2000). *Network Centric Warfare: Developing and Leveraging Information Superiority,* Command and Control Research Program (CCRP), Washington D.C.

Mitchell, P.J., Cummings, M.L.m and Sheridan, T.B. ((2004). Human Supervisory Control Issues in Network Centric Warfare, HAL2004-01, Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Cambridge, MA.

Reid, G.B., Potter, S.S., and Bressler, J.R. (1989) *Subjective Workload Assessment Technique (SWAT): A User's Guide*, AAMRL-TR-89-023, Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH.

Boff, K.R. and Lincoln, J.E. (1988) *Engineering Data Compendium, Human Perception and Performance,* Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH.

Shaughnessy, J. J. and Zechmeister, E. B.. (1990) *Research Methods in Psychology,* (2nd. Ed.). New York: *McGraw-Hill*

JV2020 (2000) *Joint Vision 2020,* Available at: http://www.dtic.mil/jointvision/jvpub2.htm Director for Strategic Plans and Policy, J5; Strategy Division, US Government Printing Office, Washington DC

JV2010 (1996) *Joint Vision 2010,* Available at: http://www.dtic.mil/jointvision/jvpub.htm Director for Strategic Plans and Policy, J5; Strategy Division, US Government Printing Office, Washington DC

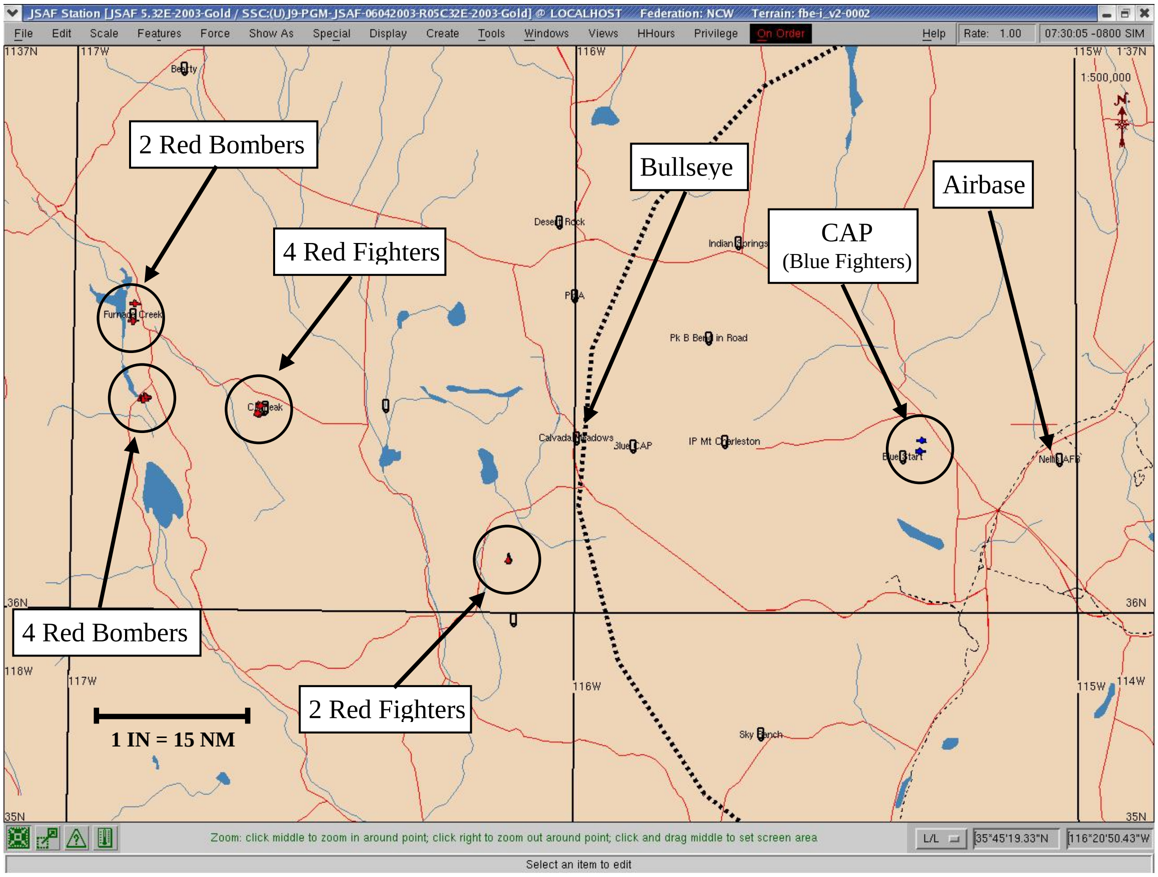
Shaw, R.L., (1985), FIGHTER COMBAT Tactics and Maneuvering, Naval Institute Press, Annapolis, MD.

APPENDIX A: RED TEAM SCENARIOS

The three scenario used for data collection had 6 fighter aircraft and 6 strike aircraft (bombers). The fighters displayed very aggressive behavior while the bombers were more passive and generally only engaged when on the defensive. The red fighters were escorts for the strikers. Their primary mission was to destroy the blue teams' aircraft to allow the strike aircraft to complete their mission of bombing the airbase.

Scenario One: This scenario begins with four fighters (2 groups of 2), at medium altitude, 30 miles west of the bullseye, two fighters at high altitude 13 miles south-southwest of the bullseye, four bombers, at medium altitude, 40 miles west of the bullseye (10 miles in trail of the lead division of fighters), and two bombers, at high altitude, 50 miles northwest of the bullseye.

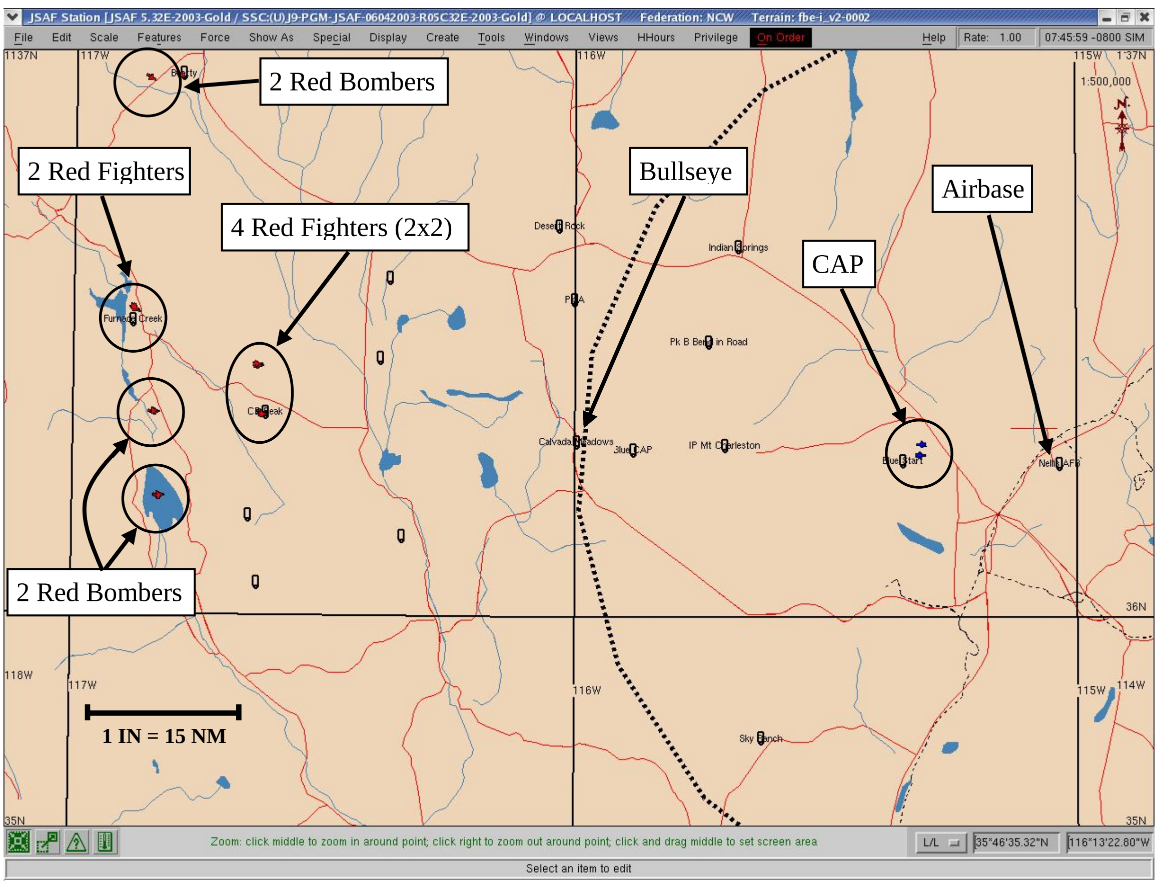
When the trial begins, the southern fighters fly a sweep from south to north and then head east toward the airbase; the northwest bombers fly a northeast to southeast arc to the airbase; the lead fighter division split into two sections, one heading northeast then east, the other southeast then east; the western bomber division flies east, then retrogrades west, then turns back east to the airbase.



Scenario 1. Screen shot of the JSAF constructive simulation tool showing the layout of scenario one. The two blue fighters are in a CAP one mile apart with one heading east and one heading

Scenario Two: This scenario begins with four fighters (two groups of two) at low altitude, 31 miles west-northwest of the bullseye. The northern group is at low altitude and southern group is at high altitude. The other two fighters are at medium altitude, seven miles in trail of the northern group. Two bombers begin 45 miles northwest of the bullseye, at high altitude. The other four bombers begin at low altitude, in a wall formation 10 miles west of the fighter sections, stacked slightly northwest to southeast

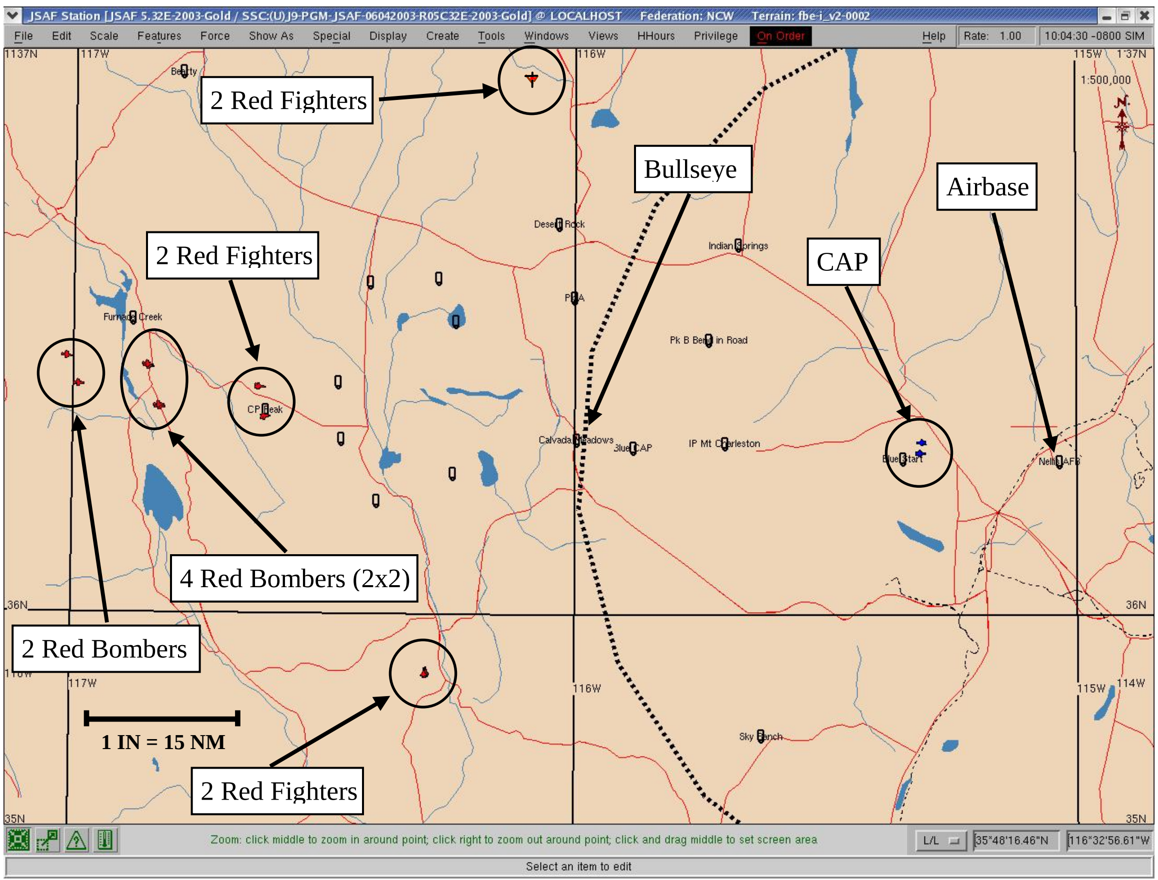
When the trial begins, the low altitude fighters flow northwest and then east; the high fighters flow directly east; the northwest bombers drive southeast to the airbase; the fighters from the wall flow southwest and then east; the bombers flow southeast, retrograde back west and then flow back to the east to the airbase



Scenario 2. Screen shot of the JSAF constructive simulation tool showing the layout of scenario one. The two blue fighters are in a CAP one mile apart with one heading east and one heading

Scenario Three: This scenario begins with two fighters 47 miles north of bullseye, at high altitude, two fighters 28 miles southwest of the bullseye, at medium altitude, and two fighters 30 miles west of the bullseye, at high altitude. Four of the bombers start 40 miles west of the bullseye, stacked medium to low. The other two bombers start 45 miles west of the bullseye, stacked high to medium

When the trial begins, the northern fighters flow south and then east; the southern fighters flow northwest then east; the lead fighters in the ladder do a cross-over and flow northeast and then east, and southeast and then east; the division of bombers split to northeast to east and southeast to east; and the section of bombers flow southeast to east to the airbase.



Scenario 3. Screen shot of the JSAF constructive simulation tool showing the layout of scenario one. The two blue fighters are in a CAP one mile apart with one heading east and one heading

APPENDIX B: INSTRUCTIONS GIVEN TO PARTICIPANTS

Purpose: The study you are participating in supports an AFRL/HEC research initiative to define and overcome the human factors issues associated with the implementation of the Network Centric Warfare concept of operations. Secretary of Defense Donald Rumsfield has stated that the DoD must transform itself from a cold war capability to one appropriate for the present threats (Transformation Planning Guidance, Department of Defense, 2003). Alberts states that Network Centric Warfare is an information superiority-enabled concept of operation that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased survivability, and a degree of self-synchronization (Network Centric Warfare, Alberts, Gartska and Stein, 1999). The Network Centric Warfare concept of operation is transformation and there are a significant number of human factors challenges inherent in its implementation. Exploratory development in this area enables AFRL/HEC to develop interface concepts that will optimize the capability of warfighters operating in future Network Centric environments.

Mission Description: You will be flying an air-to-air combat air base defense mission through hostile air space. You will have one wingman. You and your wingman are the “DIGEIE team”. Your task is to locate and destroy the computer controlled enemy bombers (whose mission is to bomb Nellis AFB that you are protecting). The scenario will also include independently manned hostile fighters whose task is to eliminate the DIGEIE team and defend the bombers. It is possible that other blue team aircraft might be returning from another mission. Those aircraft will be coming from a vector of 225 from Nellis AFB (homeplate).

Each mission will begin with the DIGEIE team flying in a Combat Air Patrol (CAP) pattern until the hostile aircraft are detected. The mission will be terminated when the DIGEIE team aircraft have successfully destroyed all the bombers OR all the bombers have crossed homeplate (Nellis AFB).

Rules of Engagement: You may employ any tactics necessary to destroy the bombers flying in toward Nellis, including destroying the enemy fighters. The threats may approach from the North, South or West of Nellis, AFB.

Additional information:
DIGEIE team radar range will vary by trial.
DIGEIE team may or may not have the assistance of a controller.
Blue team missile range 30 mi.
Red missile range approximately 21 miles.
One DIGEIE team member will start at 90 from the bullseye and the other will start at 270 from the bullseye.
Nellis AFB is approximately 30 miles East of the bullseye.

Following each trial you will be asked for some subjective workload (SWAT) and situational awareness (SART) ratings.

APPENDIX C: INFORMED CONSENT FORM

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent Document
For

Network-Centric Interface Development and Evaluation using SAFIRE

AFRL/HECP, WPAFB, OH, Building 33

Principal Investigator: Michael W. Haas, Principal Electronics Engineer, DSN 785-8768, AFRL/HECP, michael.haas@wpafb.af.mil

Associate Investigators: Shari Ulring, Human Factors Engineer, DSN 785-5112, AFRL/HECP, shari.ulring@wpafb.af.mil

1. **Nature and purpose:** You have been offered the opportunity to participate in the "SAFIRE Human-centered Simulation Architecture Evaluation" research study. Your participation will occur sometime between 15 December 2005 and 14 December 2006, in the Synthesized and human Aerospace Forces in an Immersive Research Environment (SAFIRE) at Wright-Patterson AFB. The SAFIRE is a set of distributed simulation facilities digitally linked together using distributed simulation technologies.

   The purpose of this research is to determine if the SAFIRE simulation can be used to develop and evaluate crew systems for future Air Force aircraft and ground control stations.

   The data collection time requirement for each volunteer subject is anticipated to be a total of 2 visits of approximately 3-4 hours. Training for each subject will be tailored to individual needs and progress on a self-paced schedule. The maximum training time will be approximately 16 hours spread across several days. A total of approximately 20 subjects will be enrolled in this evaluation in pairs of two. You will be required to report to the experimenter that you possess normal or corrected to normal visual acuity and normal hearing to be eligible for participation in this study.

2. **Experimental procedures:** If you decide to participate, you will be asked to sit at a desktop fighter simulator and perform air-to-air combat tasks. You will be asked to complete surveys to provide your feedback on the interface technologies and displays you experience. Testing will last 3-4 hours per day and will be done in normal lighting conditions. You will be seated during the data collection trials. You will be offered a rest period midway through the testing period but can request a break at any time during the experiment. You may withdraw this consent at any time and discontinue further participation in this evaluation without prejudice to your entitlements. Also understand that the medical monitor of this evaluation may terminate your participation in this evaluation if she or he feels this to be in your best interest.

3. **Discomfort and risks:** There is minimal risk and/or discomfort associated with performing this task. Mild postural fatigue and eye strain has been shown to be prevalent in continued computer usage but is normally alleviated with rest breaks.

4. **Precautions for female subjects:** There are no special precautions for female subjects.

5. **Benefits:** For active duty participants, there are no additional direct benefits to you for participation. Subject pool participants will be compensated monetarily at the prevailing General Dynamics AIS rate.

6. **Alternatives:** Choosing not to participate is an alternative to volunteering for this evaluation.

7. **Entitlements and confidentiality:**

   a. Records of your participation in this evaluation may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations.

   b. You understand your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the base legal office (88 ABW/JA, 257-6142 for Wright-Patterson AFB). You may contact the medical monitor, Dr. Jeff Bidinger, Maj., USAF, of this research evaluation at (937) 255-4563.

   c. If an unanticipated event (medical misadventure) occurs during your participation in this evaluation, you will be informed. If you are not competent at the time to understand the nature of the event, such information will be brought to the attention of your next of kin.

   Next of Kin if needed, Name______________________, Phone#_________________.

   d. The decision to participate in this research is completely voluntary on your part. No one has coerced or intimidated you into participating in this program. You are participating because you want to. Michael Haas, or an associate, has adequately answered any and all questions you have about this evaluation, your participation, and the procedures involved. Michael Haas can be reached at (937) 255-8768. You understand that Michael Haas, or an associate will be available to answer any questions concerning procedures throughout this evaluation. You understand that if significant new findings develop during the course of this research, which may relate to your decision to continue participation, you will be informed. You further understand that you may withdraw this consent at any time and discontinue further participation in this evaluation without prejudice to your entitlements. You also understand that the medical monitor of this evaluation may terminate your participation in this evaluation if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this evaluation

or your rights as a research subject, please contact Major Jeff Bidinger at (937) 255-4563 or jeffrey.bidinger@wpafb.af.mil.

e. You understand that your participation in this evaluation may be photographed, filmed or audio/videotaped. The audio/video data will be used for data analysis, data retrieval and backup purposes only. All audio/video media will be stored in a secure cabinet for up to 5 years in the BMC2 Lab, Bldg 33, WPAFB, OH. You understand that any release of records of your participation in this evaluation may only be disclosed according to federal law, including the Federal Privacy Act, 55 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to unauthorized sources without your permission.

f. YOU FULLY UNDERSTAND THAT YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature____Date______________

Volunteer Social Security No. (Optional)_____ ______________________________________

Advising Investigator Signature ____________________________ Date _________________

Witness Signature ____Date _________________

Privacy Act Statement

Authority: We are requesting disclosure of personal information, to include your Social Security Number. Researchers are authorized to collect personal information (including social security numbers) on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943.
Purpose: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate.
Routine Uses: Information (including name and SSN) may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this evaluation and to provide medical care.
Disclosure: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this evaluation may be impacted by a refusal to provide this information.

APPENDIX D: SACS OPERATIONS MANUAL

Introduction

The purpose of this document is to familiarize pilots and other users with the SAFIRE Air Combat Simulator (SACS) prior to participation in any simulation. This documentation should be used in conjunction with a formal hands-on training session with the simulator controls and displays.

SACS Display

The SACS display is comprised of two sections. The top section is the out-the-window scene with the Heads-up Display (HUD) overlaid. The bottom section contains instrumentation, status information, the radar display, and the tactical electronic warfare system (TEWS). The SACS display is shown below in Figure 1.

.

Figure 1 - SACS Display

THE HEADS UP DISPLAY (HUD)

The HUD contains primary flight information that permits pilots to focus their attention on what's going on outside of the cockpit without looking down at the instruments. The HUD symbology is overlaid on the out-the-window scene and shown in Figure 2.

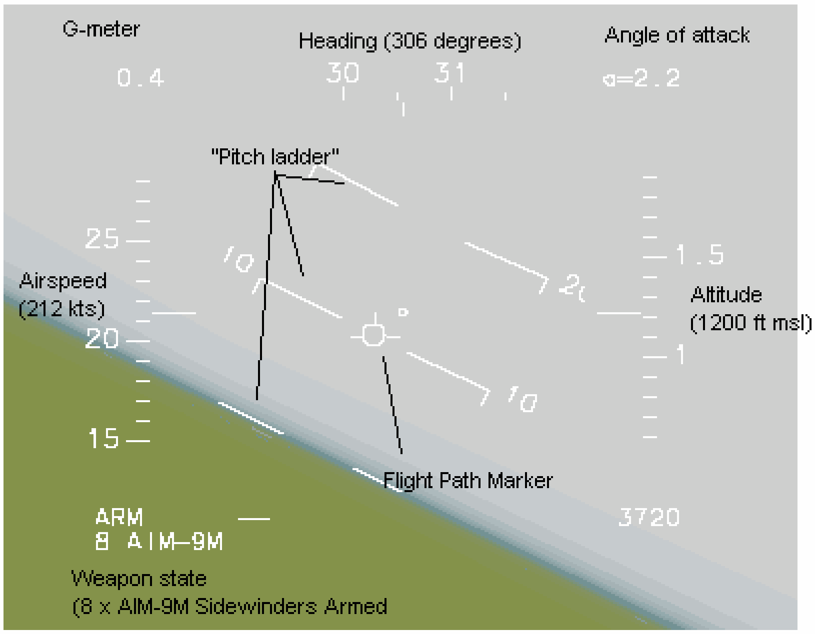


Figure 2 - SACS HUD Symbology

Airspeed Tape- On the left side of the display is the plane's true airspeed. Each major tick mark is 50 knots and each minor tick mark is 10 knots. The airspeed tape slides up and down and is read against the reference line in the middle.

Altitude Tape – The altitude tape, displayed on the right side, is similar to the airspeed tape except each major tick mark represents 500 feet and each minor tick mark is 100 feet. The altitude is defined as feet above mean sea level (MSL). . A vertical velocity readout, expressed in feet per minute, is located just below the altitude tape.

Heading Tape - In the upper center, displayed horizontally, is the heading tape. Each tick represents five degrees. The accompanying numerics are tens of degrees (i.e., 31 equals a heading of 310).

Flight Path Marker – The flight path marker is displayed in the center of the HUD as a circle with three short lines attached to it. The flight path marker indicates the instantaneous velocity vector of the aircraft (i.e., its direction of travel at any point in time).

Pitch Ladder -Centered about the flight path marker is the pitch ladder. Each line corresponds to ten degrees of aircraft pitch (solid lines for positive pitch and dashed lines for negative pitch). The pitch angle is measured against the pitch reference symbol (the small circle in the middle).

Angle of Attack - The plane's current angle of attack, expressed in degrees, is located above the altitude tape following the σ= symbols. The AC will stall at a positive angle of 30 degrees and a negative angle of -30 degrees.

G-Meter - A readout of the current vertical G-force on the pilot is located on the left-hand side, above the airspeed tape.

Weapons – The currently selected weapon status, quantity, and type is displayed below the airspeed tape. If a target has been designated by the pilot, a target designator box (a box slightly larger than the flight path marker) will be displayed at the location of the target, and the range to the target will follow the weapon status readout.

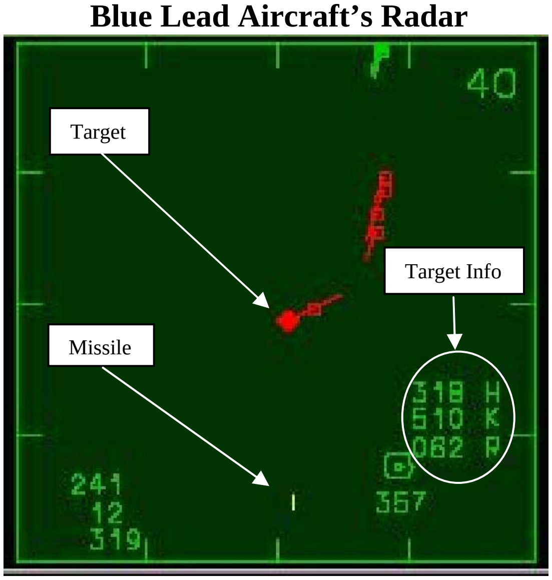
The Radar Display

The radar system has a field of view that extends +/- 60 degrees laterally and +/- 20 degrees vertically from the front of the aircraft (Figure 2). The radar coverage is roll and pitch stabilized. The radar display range is shown in the upper right hand corner of the radar display. All aircraft within that range and field of view will appear as small unfilled squares on the radar display. In addition each aircraft depicted on the display will have a line extending from the square indicating the relative direction of travel

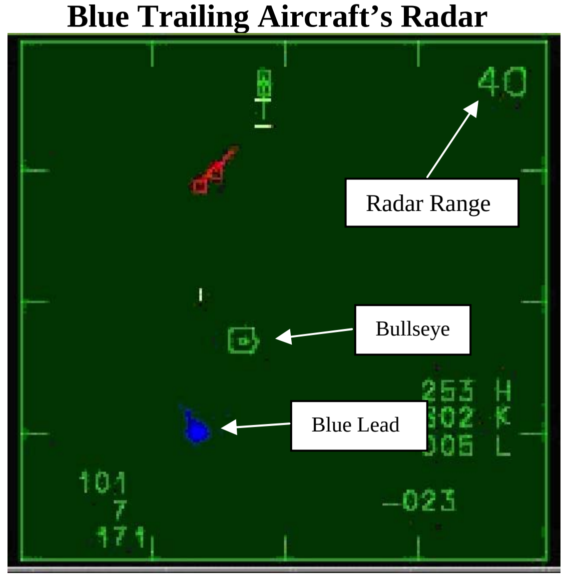
The vertical dimension of the radar display is the distance to the target. The horizontal dimension is the angle-off-nose.

Using a button on the throttle, the pilot can cycle through the displayed targets to choose one of them to be the designated target. The symbol for the designated target will change from a small unfilled square to a filled square. When a target is designated, additional information is displayed, including the target aspect angle, range to the target, and closure rate.

Blue Lead Aircraft's Radar



Blue Trailing Aircraft's Radar



Tactical Electronic Warfare System (TEWS)

The TEWS display is located just to the left of the radar display. It is the two concentric circles with the ownship symbol in the center. When radar emissions from other aircraft are detected, the system plots a box on the TEWS display in the relative direction of the radar emission. If the detected emission is beyond 20 nautical miles, the box is plotted on the perimeter of the display. As the emitting aircraft comes closer that 20 nm, the box moves inward toward the ownship symbol. The box will be colored red if the emissions are from an enemy aircraft and blue for friendly aircraft. This receiver cannot detect aircraft that have their radar emissions directed away from your aircraft, nor is it capable of detecting aircraft that have their radar sets turned completely off. An additional component of the warning system is an audio warning that gets played when an air-to-air missile has acquired a radar lock on your aircraft.

Instrumentation

Additional elements of the lower portion of the SACS display include landing gear status, throttle setting, engine RPM, current position, flaps setting, and subsystems failure indicators.

Weapon Systems

The aircraft is equipped with medium range missiles and guns/cannon. Weapon information is displayed in the lower left-hand corner of your HUD. The desired weapon is selected by using the thumb switch on the stick. The currently selected weapon is fired by pulling the trigger switch on the stick

Air-to-Air Missiles

The missiles are patterned after U.S. AIM-120 AMRAAM. These are fire-and-forget missiles with a maximum range of approximately 30 nm. Their range varies dramatically with the altitude of both aircraft and their closure rate. The missile subsystem couples with the radar system to attain targeting parameters. The missile launch status displayed on the HUD has three states, armed, locked, and no-escape. In this simulation the missiles are always armed. They transition to "locked" when the target was within range and in the radar field of view. They transition to no-escape when there is a high probability of kill based on range and closure rate. The no-escape state was achieved normally at a range of 12-15 nm.

Cannon

Cannon/guns are used to engage targets at closer range (i.e., less than 1.5 nm). The cannon is patterned after the U.S. M61-A1 Vulcan. Missions begin with 500 rounds of ammunition

When the cannon is selected, a Lead Computing Optical Sight (LCOS) reticule is displayed on the HUD. The HUD couples with the radar to provide a visible cue of the target's current range. The aiming reticule is surrounded by 12 ticks. An inner arc represents the current range to the target: each arc tick represents 1000 feet of distance. The aiming reticule moves across the HUD to show a good aiming point based on the target's range and your aircraft's pitch and turn rate. If

the range is large and or your pitch and turn rates are fast, you may see no reticule at all: the aiming point is simply out of the HUD's field of view.

A fixed cross (a "+") is displayed on the HUD to indicate the bore sight of the cannon -- the direction that the cannon's barrel is actually pointing. A good shot is possible when the target is within range and the LCOS reticule is centered on the bore site cross.

The HSI

The Horizontal Situation Indicator (HSI) is a device to aid navigation. The HSI shares space with the radar display. The desired display can be selected using a button on the stick. The HIS can be used to put the aircraft on a heading towards a selected airbase.

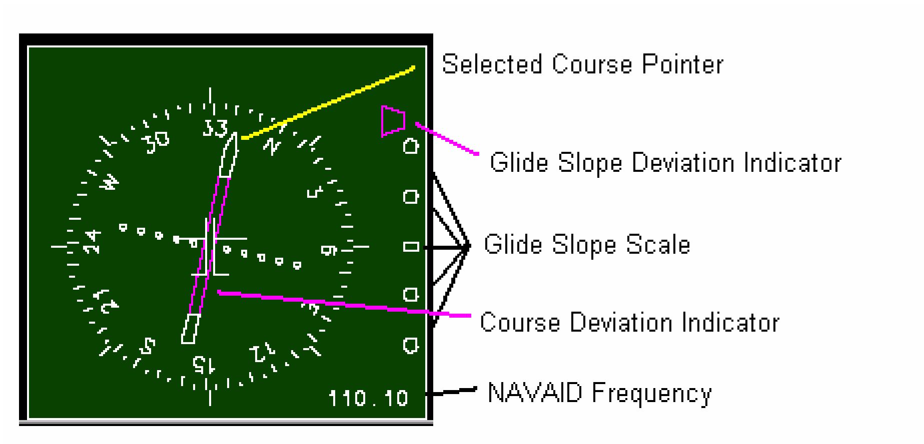


Figure 3 - SACS HSI

SACS Controls

The SACS aircraft can be piloted using a mouse and keyboard, or by attaching a stick and throttle quadrant to the computer. The list of keyboard commands can be displayed by hitting the F1 key when SACS is running. When using an attached stick and throttle, various buttons and switches are mapped to the desired keystrokes

Hands-on Throttle and Stick (HOTAS) Controls

The HOTAS control configurations are shown in Figure 4 and Figure 5. The following paragraphs describe the functionality assigned to the buttons and switches.

Point-of-View – The out-the-window scene can be generated by looking out the front of the aircraft, to the left or right, or out the back of the aircraft. The view can be changed using the top center hat (looks like a castle) on the stick.

Trim – The aircraft aerodynamics can be trimmed using the top right hat on the stick. When the aircraft is trimmed, it will remain in level flight without stick inputs. This is important to prevent hand and arm fatigue by eliminating the need for a constant bias on the stick. The aircraft may need to be re-trimmed when a new altitude and airspeed operating point is reached.

Weapon Selection – The choice between missiles and guns can be toggled using the thumb switch on the stick.

Fire – The stick trigger is used to fire the selected weapon.

Radio Communications – The pinkie switch on the stick is used as a push-to-talk switch for radio communications.

Radar Control – The cursor (top center on the back of the throttle) is used for radar functions. Pulling the cursor up cycles the designated target (if there's more than one). Moving the cursor to the right toggles the radar display between standby, normal mode, and HSI.

Speed Brake – The hat switch on the side of the throttle opens and closes the speedbrake.

Figure 4 - SACS Stick Control Functions

:

Figure 5 - SACS Throttle Functions

APPENDIX E: ACRONYM LIST

ACM	Air Combat Maneuvering
AAM	Air-to-Air Missile
AMRAAM	Advanced Medium Range Air-to-Air Missile
AOA	Angle of Attack
DIS	Distributed Interactive Simulation
ECM	Electronic Countermeasures
FPM	Flight Path Marker
HOTAS	Hands-on Throttle and Stick
HSI	Horizontal Situation Indicator
HUD	Heads-up Display
IAS	Indicated Airspeed
kts	Knots (nautical miles per hour).
KIAS	Knots Indicated Airspeed
LCOS	Lead Computing Optical Sight
RWR	Radar Warning Receiver
SACS	SAFIRE Air Combat Simulator
TAA	Target Aspect Angle
TAS	True Airspeed
VBMS	Virtual Battlespace Management System